ATHABASCA RIVER MODELLING STUDIES (PHASE 1)

FORT McMURRAY - EMBARRAS

by

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for

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ABSTRACT

The present and proposed industrial development associated with the Athabasca Oil Sands has resulted in a need to evaluate the Athabasca River transport and assimilation of contaminants and water occurring substances.

Since the beginning of AOSERP in April 1975, water quality and quantity data have been collected to provide a general baseline of information. Preliminary studies of the Athabasca River Basin indicate that a mass balance approach may be used to model the chemistry of the Athabasca River. The base model developed provides a reasonable analysis of dissolved sodium, dissolved chloride, total alkalinity, and total hardness between Fort McMurray and the Embarras Airport.

It appears possible now to investigate transformations, impacts, and assimilation of non-conservative substances in the Athabasca River utilizing the mass balance concept developed for conservative substances in the study. Once the composite model is calibrated and tested, it would predict mass loading or concentration of a parameter at any point along the study area for different future development scenarios. The resulting evaluations of these development scenerios will allow comprehensive management planning to be completed for the Athabasca watershed.

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1. INTRODUCTION

The present and proposed industrial development associated with the Athabasca Oil Sands has resulted in a need to evaluate the Athabasca River transport and assimilation of contaminants and water occurring substances. Since the beginning of AOSERP in April 1975, water quality and quantity data have been collected to provide a general baseline of information.

This report examines, in a preliminary way, available water quality and quantity information for conservative substances to assess if this information is adequate to develop a mass balance model of the Athabasca River. Recommendations have been prepared for use of the baseline data in a more comprehensive way for organic substances of interest to Alberta Environment. The report also recommends methods of slightly modifying the water quality monitoring program in order to develop more accurate assimilative models in the future.

1.1 OBJECTIVES AND SCOPE

The basic thrust of this study has been to evaluate and use all appropriate existing water quality data for conservative substances in a mass balance model. The relatively inert inorganic components have been used in effect as a "tracer". The inorganic components in the river were correlated with existing river flow and other water quality information for the Athabasca River above and below the study region, and for all the major tributaries monitored for flow and water quality. The method provided preliminary information on possible river sinks and sources throughout its length.

In order to accomplish the above objectives, a three-phase program was recommended by IEC:

1. Complete several initial system correlations of data on inorganic tracers and the Athabasca River flow to establish if the mass balance approach is applicable.
2. Evaluate for the entire study region the existing water quality information pertinent to the Athabasca River Basin and establish the suitability of this information for a future model of the river.
3. Make recommendations to Alberta Environment regarding present and future water quality monitoring programs from the perspective of using the information in future river models. Considering the dynamics of biochemical reactions, groundwater sources and sinks, and physical-chemical factors, these recommendations could be of interest to Alberta Environment.

After the data review was completed, the originally proposed computer data evaluation was not deemed applicable for this work. The original approach, however, may be suitable for future work.

As the model is developed, it will make possible future predictions of water quality for parameters of concern to Alberta Environment. Present and future water quality monitoring and other research investigations could utilize information provided by this model. It would also be possible to estimate the impact of chemicals or pollution components which have not been monitored but which are of interest to Alberta Environment. To do this, however, a more comprehensive model of the river would have to be developed.

1.2 STUDY AREA

The reach of the Athabasca River between Fort McMurray and Embarras Airport (Figure 1) was chosen for the study because of the extensive oil sands development in the area and the availability of flow data at the two locations.

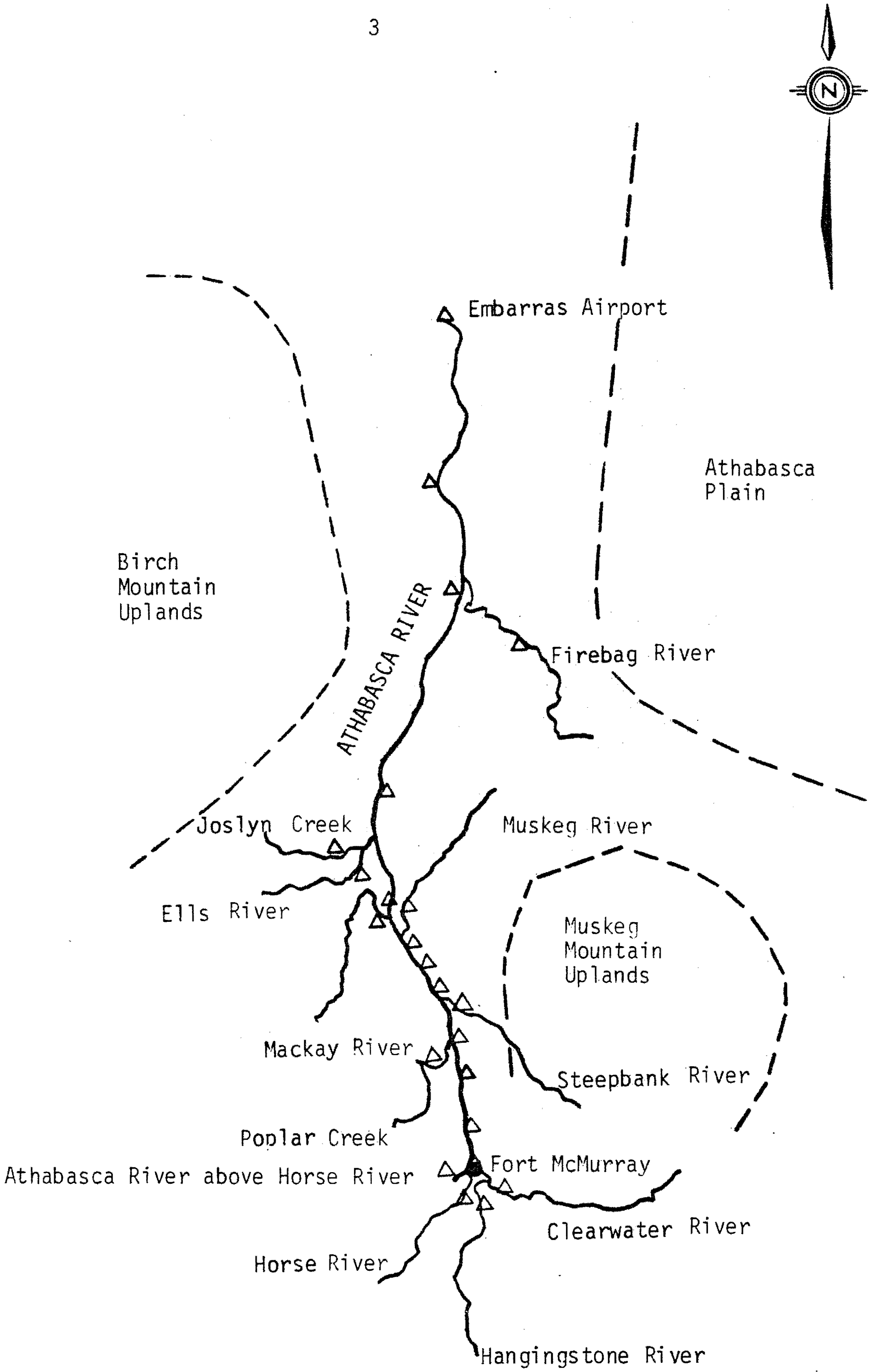

Figure 1. Project study area. (△ : water quality stations)

The main tributaries considered in this study are the Horse, Hangingstone, and Clearwater rivers, which join the Athabasca River near Fort McMurray; the major streams from the east slopes of the Birch Mountains, including Ells, MacKay, Beaver/Poplar, and Joslyn; and to the east the Firebag, Muskeg, and Steepbank rivers.

Taking the flow at Embarras Airport as 100%, approximately 3.3% comes from the eastern slopes of Birch Mountains, 5.0% comes from the bank to the east of Athabasca, and the remaining comes from just downstream of Fort McMurray (Neill and Evans 1979).

2. SOURCES OF DATA

2.1 STREAM FLOW DATA

All flow data used in this report were obtained from Inland Waters Directorate, Water Resources Branch of Environment Canada.

The overall accuracy of the flow data depends upon the stability of the stage-discharge relationship, the frequency of measurements and the accuracy of observations. In general, data collected during open-water periods are more reliable than those collected during periods of ice conditions. The associated error with individual flow measurements is in the range of ± 10% to 15%.

The high and variable flows from spring runoffs are not suitable for river modelling and were not used in the analysis.

2.2 WATER QUALITY DATA

All water quality data were supplied by AOSERP water quality branch.

Although the accuracy of the quality data was published as well within ± 5% range for the parameters analyzed in this study (Standard Methods 1965), there are significant variations for some data. For example, at Station DA-0204 on 29 June 1976, the measured concentration of total hardness decreased from 107.0 mg/L to 91.2 mg/L in 10 min. (107.0 mg/L and 91.2 mg/L correspond to right and left bank concentrations, respectively.) In all such cases, the average of the two or more values were used for this study. This problem of fluctuating data is further discussed in Section 6. Precautions were taken to ensure that the measurements during spring runoff periods and during storm events were excluded.

3. ANALYSIS

3.1 TIME OF TRAVEL

A river time of travel is, to a large extent, a function of the hydraulic profile of the river surface. The hydraulic profile of the Athabasca River (Figure 2) has been presented extensively in other reports (Kellerhals et al. 1972). Visual inspection of the profile showed that the water surface slope is fairly constant from Fort McMurray to Embarras. The distance for this reach was reported to be 181.2 km with a total vertical drop of 22.8 m, thus giving an average slope of approximate 0.013% during open water periods. Average slopes for sub-reaches of the Athabasca River are presented in Table 1.

The time of travel will be different for ice and no-ice conditions. It has been computed separately as follows:

Ice Conditions

Based on the AOSERP report entitled "Mixing Characteristics of the Athabasca River below Fort McMurray-Winter Conditions" (Beltaos 1979), the average velocity in the river under ice conditions was estimated to be approximately 0.42 m/s. This estimate is based on two slug tests done in February 1978 at a flow rate of 241.5 m^3/sec. Using this average velocity, the time of travel from Fort McMurray to Embarras under ice conditions would be approximately 5 d.

Open-Water Conditions

Water-level charts for four apparent storms in the study region were obtained from Environment Canada, Water Resources Branch. From these charts, the apparent time for a surface wave to travel between Fort McMurray and Embarras was estimated by IEC to be 1.883 for a flow range of 966 m^3/s to 2804 m^3/s. It is well known that, in many cases, particularly for within-bank flow, the front of a flood wave travels down a river with a speed greater than the mean water velocity at any cross section of the wave (Rouse 1950).

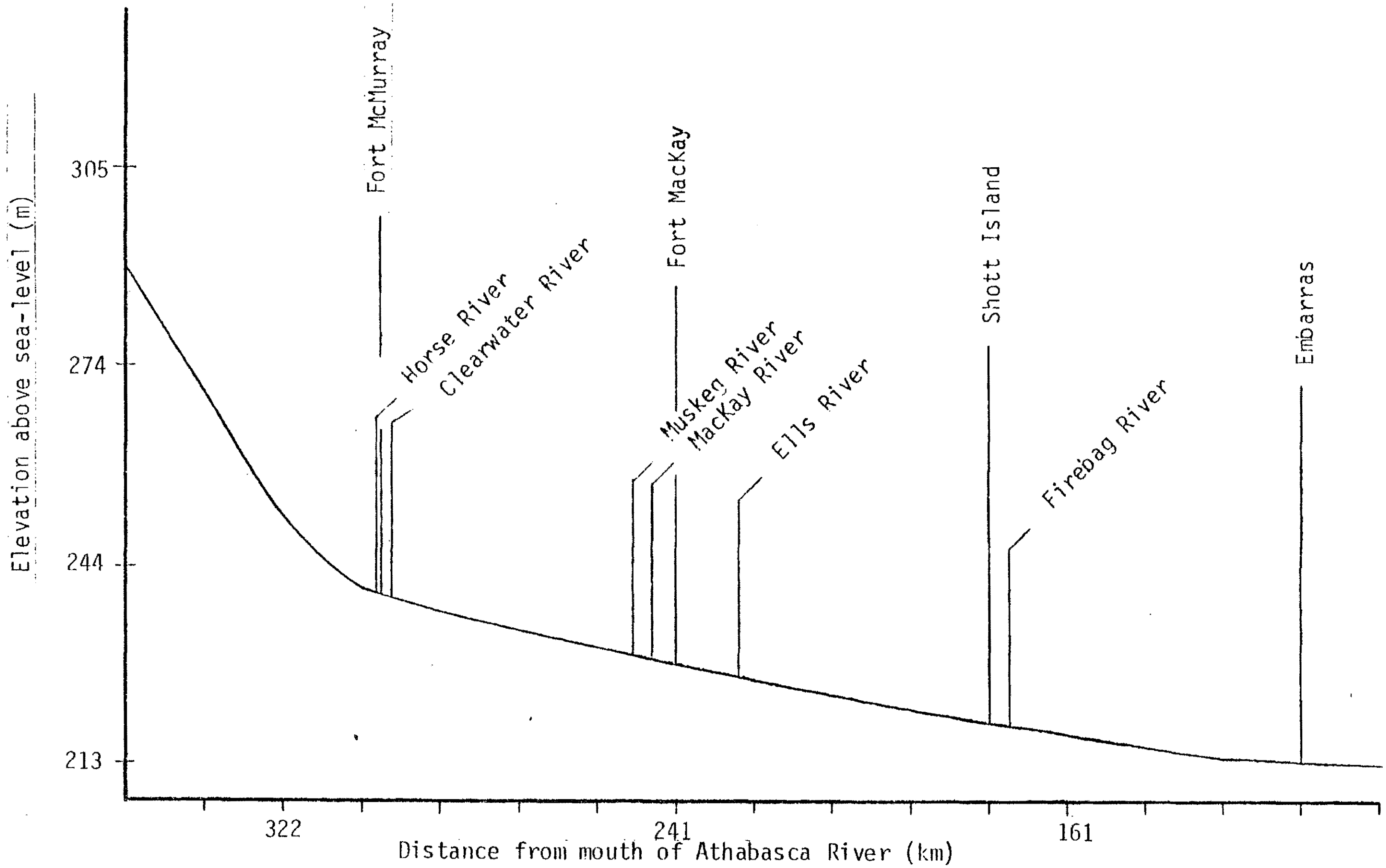

Figure 2. Athabasca River: Hydraulic profile between Fort McMurray and Embarras (Kellerhals et al. 1972).

Table 1. Longitudinal profile of the Athabasca River between Fort McMurray and Embarras.

Reach	Distance (km)	Average Slope (%)
Fort McMurray to Fort Mackay	53.8	0.0144
Fort Mackay to Shott Island	65.0	0.0121
Shott Island to Embarras	62.4	0.0113

Source: Kellerhals et al. 1972.

The ratio of the wave velocity to the actual velocity for a channel of wide rectangular cross-section has been estimated at approximately 1.50. As an approximation, the time of travel under no-ice conditions could be estimated at 2.825 d. For the purpose of this preliminary study, the time of travel has been assumed to be independent of the flow rate. The estimated time of travel from Fort McMurray to the confluence of each major tributary is outlined in Table 2.

3.2 RELATIONSHIPS BETWEEN FLOW, MASS, AND CONCENTRATION

Figures 7 through 70 in the Appendix present the plots of measured flow in m^3/s versus measured concentration in mg/L. (Due to the large volume of figures, these graphs are appended rather than being included in the body of the report.) Mass loading in t/d has been calculated and plotted for dissolved sodium, dissolved chloride, total alkalinity, and total hardness at each of the selected stations.

The results represent the data collected from 1976 to 1980 that are available through Alberta Environment. The number of data points has been reduced by excluding spring runoff and data collected during storm events. In most cases, the shape of the concentration curves appears generally asypmtotic with high concentrations during low flows (usually under ice cover conditions) and low concentration at high flows. No attempt was made to fit curves to the concentration data as only mass loading data have been used in this study.

The mass curves are typically parabolic at low flows and linear at higher flows. Regression techniques were applied for specific ranges where a linear fit appeared appropriate.

The figures indicate that a very good linear correlation exists between flow and the mass loading of total alkalinity and total hardness. For these linear relationships, the coefficient of correlation ranged from 0.754 to 0.996. The slope of the mass curves also indicated that Poplar Creek, Muskeg River, and Joslyn Creek have high loadings of total alkalinity and total hardness.

Table 2. Estimated time of travel in the Athabasca River.

From[a]		To		Estimated Time of Travel (d)	
				Ice	No-Ice
0201	Fort McMurray	0070	Poplar Creek	0.71	0.40
0300	Horse	0060	Steepbank	0.95	0.54
0040	Hangingstone	0080	Muskeg	1.40	0.79
2300	Clearwater	0011	Mackay	1.42	0.80
		0170	Ells	1.86	1.05
		0160	Joslyn	1.86	1.05
		0010	Firebag	3.35	1.90
		0010	Embarras	4.99	2.83

[a]Because of the proximity of stations 0300 Horse, 0040 Hangingstone, and 2300 Clearwater to 0201 Fort McMurray, these stations have been approximated as the same location for purposes of time-of-travel calculations.

A fairly good linear correlation exists between flow and dissolved sodium mass loading, except for stations on the larger rivers, e.g., the two Athabasca stations and the Clearwater River station. Some of the tributaries have relatively high sodium concentration, notably the Hangingstone River, Poplar Creek, and Joslyn Creek.

Flow versus dissolved chloride mass loading appears to have a relatively poor correlation. Hangingstone River and Poplar Creek have much higher chloride loading than the others.

Tables 3 through 6 provide the regression equations, applicable flow range, and correlation coefficients for Figures 7 through 70.

There is a lack of available data both in terms of flow and quality for some stations, specifically Horse and Ells rivers. However, since the flow of these two streams is relatively small, the effect would be insignificant. Unfortunately, information is also limited for the two Athabasca stations which are very significant for water quality modelling. For example, very little water quality information is available at the station below Fort McMurray where daily flow records are available. In an attempt to compensate for this limited data, the water quality data at the station above Horse River were used with adjusted flows. In these calculations, four sets of flow records were used, including Athabasca below Fort McMurray, Horse River, Hangingstone River, and Clearwater River. Since there is a certain amount of error associated with each set of flow data, the end results obtained by using four sets of data could include a larger degree of uncertainty than for any other station. Similar difficulties were encountered in utilizing the limited water quality data at Embarras. In addition, much of the winter flow records are missing for 1977, 1978, and 1979 at this station. Since the Athabasca stations represent 72.0% of the total flow at the point above Horse River and 100.0% of the total flow at Embarras, the lack of quality and quantity data provided some difficulties in completing this study. It is recommended that more extensive data be collected for the Athabasca River in the future.

Table 3. Regression data -- dissolved Na: Flow (m^3/s) vs. mass loading (t/d).

Location	Correlation Coefficient	Slope of Equation	y-intercept	No. of Observations Used	Applicable Flow Range (m^3/s)
Athabasca above Horse	N/A	N/A	N/A	25	N/A
Horse	0.980	0.691	2.528	11	1.0 to 9.0
Hangingstone	0.969	1.547	1.141	19	0.6 to 6.0
Clearwater	0.920	0.804	120.200	23	50.0 to 210.0
Athabasca between Clearwater & Poplar	0.950	0.444	156.58	18	200.0 to 1500.0
Poplar	0.958	2.049	0.980	20	0.5 to 3.0
Steepbank	0.918	0.548	1.400	24	0.6 to 7.0
Athabasca between Steepbank & Muskeg	N/A	N/A	N/A	11	N/A
Muskeg	0.994	0.997	0.106	19	0 to 3.5
Mackay	0.983	0.723	4.760	31	4.0 to 35.0
Athabasca below MacKay	N/A	N/A	N/A	19	N/A
Ells	0.963	0.764	0.435	12	0.4 to 6.0
Joslyn	0.937	2.203	0.059	18	0 to 0.6
Athabasca between Joslyn & Firebag	N/A	N/A	N/A	8	N/A
Firebag	0.968	0.222	1.331	27	8.0 to 60.0
Athabasca at Embarras	0.847	0.497	342.130	18	400.0 to 1900.0

N/A: not applicable

Table 4. Regression data -- dissolved Cl: Flow (m^3/s) vs. mass loading (t/d).

Location	Correlation Coefficient	Slope of Equation	y-intercept	No. of Observations Used	Applicable Flow Range (m^3/s)
Athabasca above Horse	N/A	N/A	N/A	21	N/A
Horse	N/A	N/A	N/A	N/A	N/A
Hangingstone	0.981	1.339	0.410	20	0.8
Clearwater	0.917	0.987	169.238	23	50.0 to 200.0
Athabasca between Clearwater & Poplar	0.754	0.086	77.32	18	200.0 to 1500.0
Poplar	0.916	1.251	0.653	26	0.5 to 3.0
Steepbank	0.967	0.153	0.186	23	0.8 to 6.0
Athabasca between Steepbank & Muskeg	N/A	N/A	N/A	11	N/A
Muskeg	0.980	0.325	0.051	19	0.4 to 3.5
Mackay	0.904	0.167	1.360	32	5.0 to 35.0
Athabasca below Mackay	N/A	N/A	N/A	19	N/A
Ells	0.959	0.138	0.084	12	0.4 to 6.0
Joslyn	0.766	0.180	0.012	16	0.12 to 0.6
Athabasca between Joslyn & Firebag	N/A	N/A	N/A	7	N/A
Firebag	0.923	0.100	1.092	29	8.0 to 60.0
Athabasca at Embarras	N/A	N/A	N/A	21	N/A

N/A - Not applicable

Table 5. Regression data -- total alkalinity: Flow (m^3/s) vs. mass loading (t/d).

Location	Correlation Coefficient	Slope of Equation	y-intercept	No. of Observations Used	Applicable Flow Range (m^3/s)
Athabasca above Horse	0.980	7.014	1007.438	29	300.0 to 1200.0
Horse	0.973	4.394	16.880	11	1.0 to 9.0
Hangingstone	0.963	6.331	7.789	13	1.0 to 5.0
Clearwater	0.958	4.417	66.608	22	50.0 to 190.0
Athabasca between Clearwater & Poplar	0.992	7.890	795.920	14	200.0 to 1200.0
Poplar	0.982	10.384	0.761	25	0 to 3.0
Steepbank	0.963	6.248	10.487	18	1.0 to 7.0
Athabasca between Steepbank & Muskeg	0.996	7.470	512.600	10	200.0 to 900.0
Muskeg	0.995	13.088	3.666	16	0.3 to 3.5
Mackay	0.962	6.232	20.225	32	3.0 to 35.0
Athabasca below Mackay	0.964	6.270	1314.750	25	400.0 to 1800.0
Ells	0.985	7.194	1.124	14	0.2 to 6.0
Joslyn	0.957	12.168	0.237	18	0.04 to 0.5
Athabasca between Joslyn & Firebag	0.992	6.810	688.620	8	200.0 to 800.0
Firebag	0.992	6.612	41.521	29	6.0 to 50.0
Athabasca at Embarras	0.986	7.246	753.950	25	150.0 to 1900.0

Table 6. Regression data -- total hardness: Flow (m^3/s) vs. mass loading (t/d).

Location	Correlation Coefficient	Slope of Equation	y-intercept	No. of Observations Used	Applicable Flow Range (m^3/s)
Athabasca above Horse	0.993	8.664	867.9	25	50.0 to 900.0
Horse	N/A	N/A	N/A	11	N/A
Hangingstone	0.984	7.185	5.136	21	1.0 to 6.0
Clearwater	0.958	4.519	76.494	22	60.0 to 210.0
Athabasca between Clearwater & Poplar	0.991	9.130	951.840	15	220.0 to 1200.0
Poplar	0.993	9.386	0.266	27	0 to 3.0
Steepbank	0.963	6.184	6.811	23	0.8 to 7.0
Athabasca between Steepbank & Muskeg	0.996	8.060	578.320	11	200.0 to 900.0
Muskeg	0.995	12.924	2.720	19	0.6 to 3.5
Mackay	0.976	6.197	16.433	32	3.0 to 35.0
Athabasca below Mackay	0.963	6.490	1577.17	26	400.0 to 1800.0
Ells	0.972	6.069	3.905	15	1.4 to 7.4
Joslyn	0.978	13.598	0.251	18	0.1 to 0.5
Athabasca between Joslyn & Firebag	0.993	7.920	699.180	8	200.0 to 800.0
Firebag	0.982	6.583	44.337	29	18.0 to 50.0
Athabasca at Embarras	0.953	6.682	1907.850	17	400.0 to 1900.0

N/A - Not applicable

4. APPLICATIONS

Plots of flow versus mass loading for each of the stations were used to estimate the mass loading of any of the four parameters considered at a specified flow and location. The procedure is summarized as follows:

A date was selected when relatively steady flow conditions existed and water quality data were available at Embarras. Using the recorded flow, the mass loading was computed in t/d. This was considered to be the measured or actual mass loading at that point.

By utilizing the estimated time of travel, it was possible to determine the flow contribution from the Athabasca River above the confluence of the Horse River 2.82 d previously. (See Section 3.0.) Using the appropriate time of travel, flow and mass loading were calculated for downstream stations. The resulting flow and mass contributions were summed from the Athabasca River station above Horse to the station below Firebag. This provided an estimate for the flow and mass loading at Embarras. Subtraction of the estimated flow and mass loading from the actual measured flow and mass loading gives the flow/mass loading required to balance that reach of the river (Δ flow and Δ mass).

For each of the four parameters, this procedure was repeated 10 times with no-ice conditions, and 5 times with ice-cover contitions.

Table 7 summarizes the results of the flow and mass balance techniques described above. For ease of comparison, the results are expressed as a percent of the measured data. A negative sign implies that the estimated is less than measured.

Table 7. Flow and mass balance summary.[a]

Parameter & Condition	Flow to Balance Range (%)	Flow to Balance Mean (%)	Mass to Balance Range (%)	Mass to Balance Mean (%)
Na				
no-ice	-6.16 to + 5.08	+0.55	-27.63 to -10.35	-22.30
ice	-3.23 to +10.22	+2.64	-30.52 to - 0.30	-11.69
Cl				
no-ice	-6.16 to + 5.08	+0.55	-50.21 to -25.0	-37.28
ice	-3.23 to +10.22	+2.64	-56.59 to -15.99	-31.53
Alkalinity				
no-ice	-6.16 to + 5.08	+0.55	-11.84 to +18.38	+0.51
ice	-3.23 to +10.22	+2.64	- 6.55 to + 9.14	+1.03
Hardness				
no-ice	-6.16 to + 5.08	+0.55	-10.39 to +16.13	+2.02
ice	-3.23 to +10.22	+2.64	-11.64 to +10.81	+1.04

[a] A discussion of the results presented in this table can be found on pages 20 and 21.

Outlined below is a numerical example of the procedure described and presented in Table 8.

On 21 Oct. 1977, 107.8 mg/L of total hardness was measured at the Athabasca River near Embarras. The corresponding flow rate at the same place and time was measured at 736.3 m^3/s. The measured mass was calculated to be 6855 t/d. Since open-water conditions existed at that time, the time of travel was 2.83 d or approximately 3 d (T = 3).

On 18 Oct. (T = 0), the flow rates for Horse River, Hangingstone River, and Clearwater River were 8.24 m^3/s, 4.87 m^3/s, and 137.64 m^3/s respectively. Figures 56, 57, and 58 show the corresponding mass loadings for these flow rates to be 47.9 t/d, 40.1 t/d and 698.5 t/d, respectively.

From flow records, on 18 Oct. the flow rate at Athabasca below Clearwater was 688.18 m^3/s. The flow above Horse River was therefore approximately:

$688.18\ m^3/s - 8.24\ m^3/s - 4.87\ m^3/s - 137.64\ m^3/s = 537.43\ m^3/s$.

The mass loading at this flow rate according to Figure 55 was 5524.2 t/d.

To calculate the flow contribution of Poplar Creek, it had been shown that the time of travel from above Horse River to the confluence of Poplar Creek is approximately 0.4 d. Since the flow records are conveniently available on a daily basis, the flow of Poplar Creek at t = 0.4 was estimated by multiplying 0.4 by the difference of flow between 18 and 19 Oct. This figure then was added or subtracted from the flow of 18 Oct. depending on increasing or decreasing flow. In this case, on 18 Oct., the flow was recorded at 0.74 m^3/s and on 19 Oct. 0.73 m^3/s; the difference of 0.01 is multiplied by 0.4 to obtain 0.004 m^3/s. Since the flow was smaller on 19 Oct. than 18 Oct., the flow at t = 0.4 was estimated to be 0.74 - 0.004 = 0.736 m^3/s or 0.74 m^3/s corrected to two decimal places.

Table 8. Flow and mass balance sample calculation (study period: 18 to 21 October 1977; no-ice conditions; parameter: total hardness as $CaCO_3$).

Station	Time of travel (d)	Flow (m^3/s)	Mass (t/d)
0012 Athabasca above Horse	0.00	537.43	5524.2
0300 Horse	0.00	8.24	47.9
0040 Hangingstone	0.00	4.87	40.1
2300 Clearwater	0.00	137.64	698.5
0070 Poplar Creek	0.40	0.74	7.2
0060 Steepbank	0.54	3.20	26.6
0080 Muskeg	0.79	4.49	60.7
0011 Mackay	0.80	7.91	65.4
0170 Ells	1.05	5.05	34.6
0160 Joslyn	1.05	0.49	6.2
0010 Firebag	1.90	26.37	217.9
Total		736.39	6729.3
Athabasca Actual Data Stn. 0010 at Embarras 107.8 mg/L 21 October	2.83	736.39	6855.0
% Difference: Total/Embarras		+0.01%	-1.83%

The same procedure was repeated for the computations of the flow contributions for Steepbank River at T = 0.54; for Muskeg River at T = 0.79; for Mackay River at T = 0.80; for Ells River and Joslyn Creek at T = 1.05; and for Firebag River at T = 1.90. After all the flow rates were obtained, Figures 60 to 69 were used to estimate the corresponding mass loading. The results are shown on Table 8.

At this point, the flow and mass loading of total hardness between Horse River and Embarras between 18 and 21 October 1977 had been theoretically accounted for.

The individual flow contributions above Embarras were summed to give a total estimated flow of 736.39 m^3/s below Firebag River compared to a recorded flow of 736.32 m^3/s at Embarras. The difference of 0.06 m^3/s indicated that the flow had been over-estimated by 0.01%.

The individual mass contributions above Embarras were summed to give a total estimated mass of 6729.3 t/d of total hardness as $CaCO_3$ below Firebag compared to a measure mass of 6855 t/d at Embarras. The difference of 125.7 t/d indicated that the mass had been under-estimated by 1.83%. Alternatively, one could compare the estimated concentration with the measured. The estimated concentration could be obtained by dividing the mass by the flow, resulting in a calculated concentration of 105.8 mg/L compared to a measured concentration of 107.8 mg/L.

4.1 FLOW BALANCES

During open-water conditions, the calculations showed that the combined flow of the 10 tributaries and the flow of the Athabasca River above Horse River were within $\pm$ 5% of the flow measured at Embarras Airport. During winter or ice-cover conditions the percent error increased to $\pm$ 10%. Since there is a similar or greater error associated with each gauging station, these ranges of error are considered acceptable.

4.2 MASS BALANCES

As indicated in Table 7, the outlined mean of the mass balance accounted for essentially all of the total alkalinity and hardness of the Athabasca River between Fort McMurray and Embarras. By contrast, only about 72% of sodium and 60% of chloride can be accounted for.

To provide further information, existing data from nine water quality stations on the Athabasca River were used to establish a mass balance for sub-reaches as shown in Figures 3 through 6 for sodium, chloride, alkalinity, and hardness, respectively.

The data were reviewed and reduced to represent six reference points along the reach of the study area. They are above Horse (0012); below Clearwater (201 and 203); below Steepbank (204, 205, and 206); below Mackay (207); below Joslyn (208 and 209); and below Embarras (0010). However, no relationship could be drawn for chloride at below Clearwater and below Steepbank. The mean and standard deviation of the data are indicated at each reference point.

The plots of sodium and chloride (Figures 3 and 4), indicated that possible unidentified sources exist between the confluences of Steepbank River and Joslyn Creek, whereas the profile of alkalinity and hardness show little deviation from the field measurements (Figures 5 and 6). Caution should be taken when interpreting these results since the degree of mixing is not known. Further discussions on obtaining water quality data that would take the effect of mixing into account can be found in Section 6.

In an attempt to identify possible sources of sodium and chloride, other hydrogeological studies of this area were reviewed. Smith, et al (1979) suggesed that, in some deeper wells in the study area, the influence of bedroc aquifers is reflected by higher sodium and chloride concentrations. However, direct groundwater contribution into the Athabasca River in terms of flow volume is not believed to be substantial. In the same report, it was also noted that the volume of deeper groundwater, produced as a consequence of surface mining operations at oil sands plants, may be of significance. Such groundwater, once pumped out of the ground, must be disposed of by impoundment by discharge into existing watercourses, or by reinjection into the subsurface either directly or possibly through infiltration into the groundwater flowing to the rivers.

It has also been documented (Gorrell et al. 1974) that the chloride content of the lower McMurray groundwater varies considerably. There is some chemical evidence to indicate that the groundwater of the lower part has higher chloride salinities than that in the upper part. This may be due to the vertical connection with the highly saline Devonian waters. The waters of La Saline spring which discharge into the Athabasca River at an unknown rate has a reported chloride concentration of 39 792 ppm (Gorrell et al. 1974). At this concentration, a flow of only 0.08 m^3/s is required to close the balance for chloride. Since the location of this spring is just north of the confluence of the Steepbank and Athabasca rivers, this may explain why the mass balance profile for chloride starts to dip below Steepbank as shown in Figure 4.

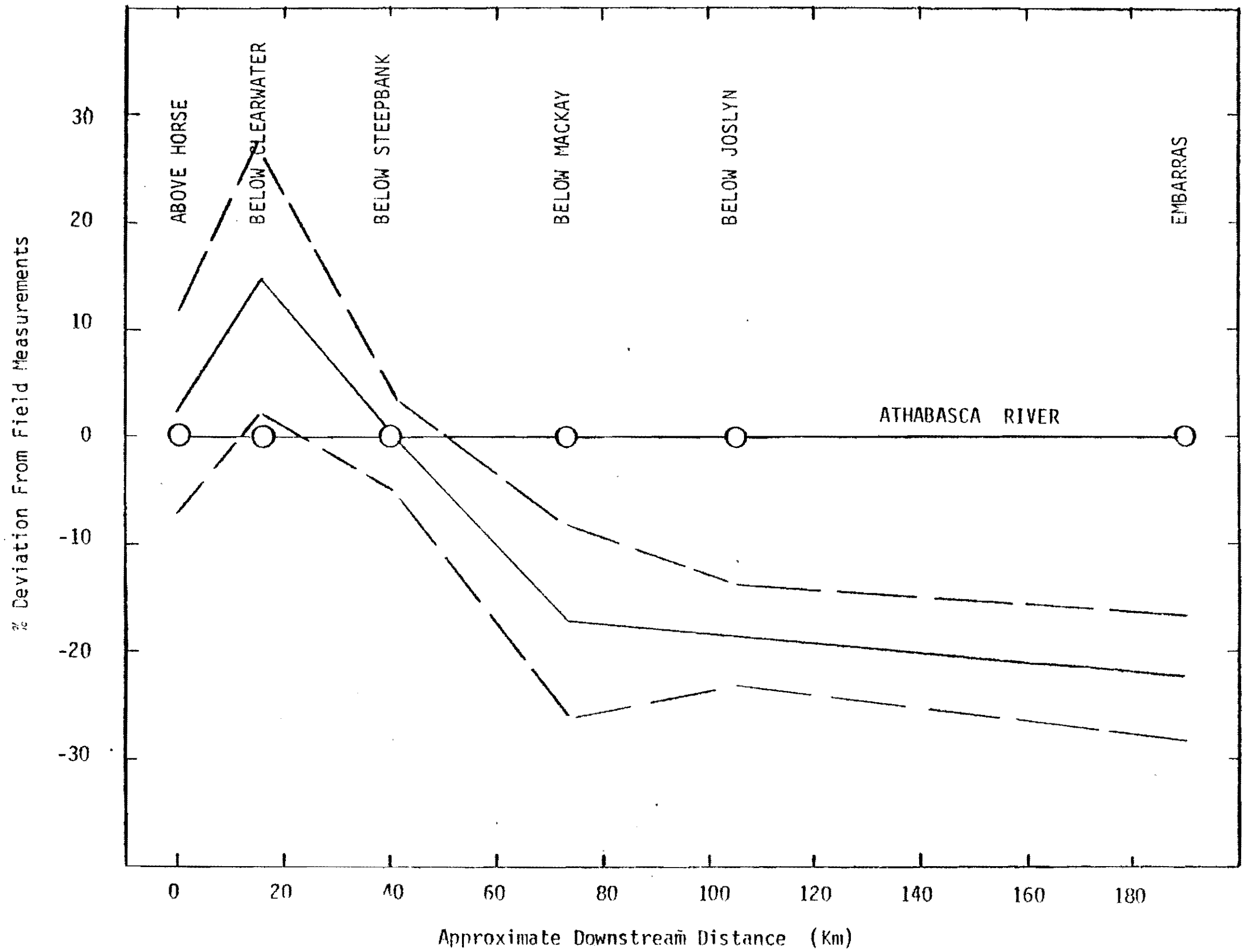

Figure 3. Mass balance profile: Dissolved Na (———: Mean, -------: 1 Std. Dev.).

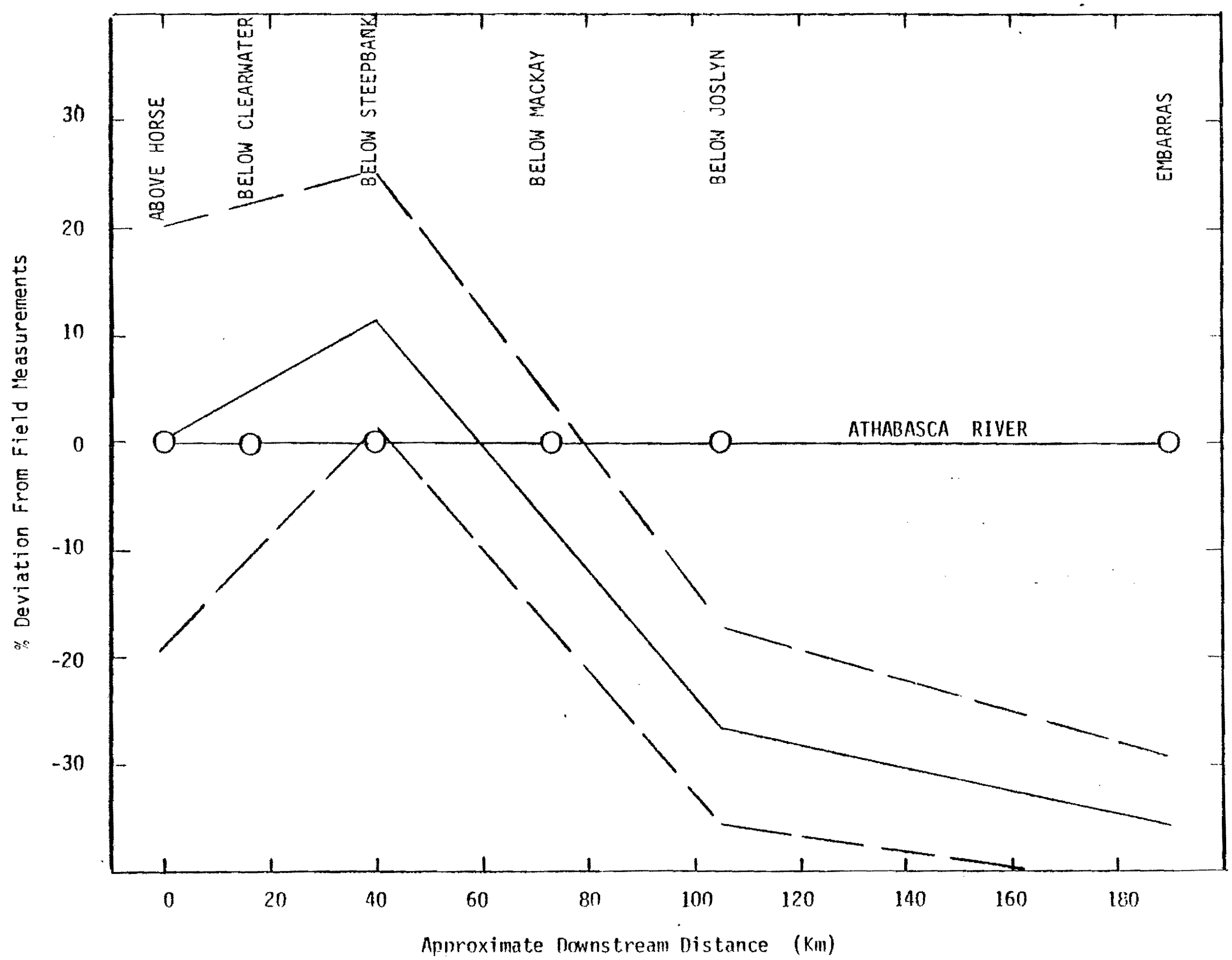

Figure 4. Mass balance profile: Dissolved Cl (——: Mean, ------: 1 Std. Dev.).

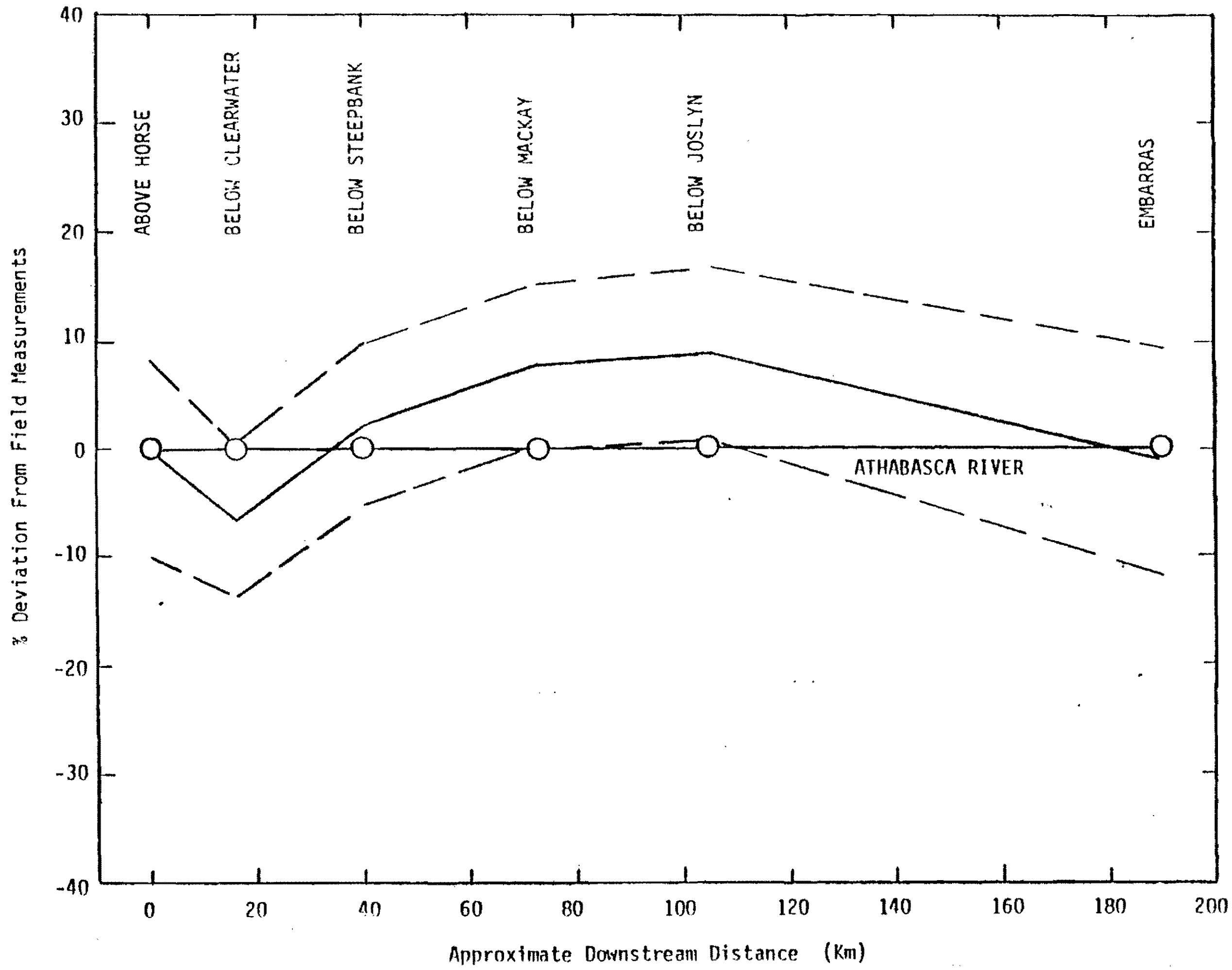

Figure 5. Mass balance profile: Dissolved alkalinity (———: Mean; -------: 1 Std. Dev.).

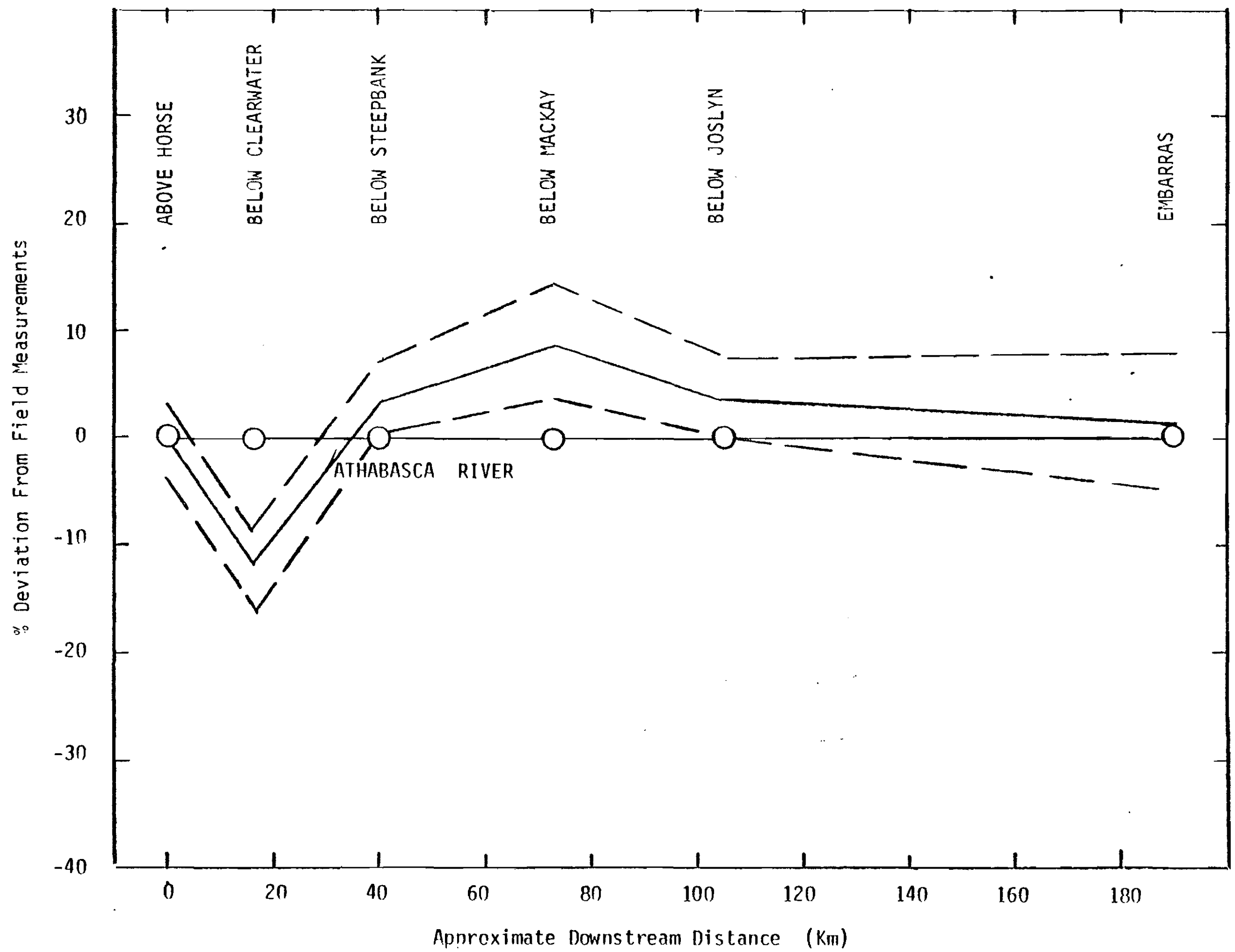

Figure 6. Mass balance profile: Total hardness (———: Mean,-------: 1 Std. Dev.).

5. PRECISION

As mentioned in Section 4, each of the ranges given in Table 7 is the result of 10 mass balance calculations at different dates and flows. It is in IEC's opinion that, although the method indicates general trends and establishes the validity of this approach, there is not sufficient information available to quantify the various inputs. More field measurements coupled with more sophisticated curve fitting techniques would improve the precision of this approach.

It has also been noted that some of the larger streams such as the Athabasca River, Clearwater River, and Firebag River contribute most of the estimated mass loading. Increasing the precision of the mass flow relationship for these stations would improve the overall precision significantly.

6. RECOMMENDED WATER QUALITY MONITORING PROGRAM

It is recognized that the objectives and implementation methods for a generalized water quality monitoring program differ substantially from monitoring for river modelling and management analyses. However, the existing water quality monitoring programs could be modified slightly in the future to permit use of the data for not only general water quality monitoring, but also for river modelling and management analyses as outlined below:

Frequency

Once per month sampling at normal steady state flow conditions should be adequate for high priority parameters. During March, April, and May the high and variable flow from spring runoff period is not suitable for river modelling and consequently, sampling is not required.

Sequence

Preferably, sequential sampling should be used to correspond to the estimated time of travel. Sampling on the Athabasca River and the tributaries should start upstream and progress downstream at a rate approximating the time of travel of the water, ideally within a range of ± 6. That is, in the summer months, if a sample is to be taken at 0900 h 1 August 81, effort should be made to sample 0300 Horse, 0040 Hangingstone, 2300 Clearwater, 0201 Athabasca, 0203 Athabasca, 0070 Poplar, 0060 Steepbank, 0204 Athabasca, 0205 Athabasca, 0206 Athabasca, 0080 Muskeg, and 0011 Mackay on the same day, in that order, when possible finishing the day's activity at 0011 Mackay at approximately 1920 h. Stations 0170 Ells, 0160 Joslyn, and 0208 Athabasca should be sampled the morning of 2 August 81; stations 0209 Athabasca and 0010 Firebag the morning of 3 August 81; and Station 0010 Embarras the morning of 4 August 81.

During the winter months when the streams are under ice-covered conditions, the same sequence should be applied but the sampling duration should increase by 76% due to longer time of travel, i.e., the sampling at Embarras should take place 5 d after the sampling at 0012 Athabasca. The above sampling procedures would be ideal from the perspective of using the monitoring program data for modelling purposes. Whether or not these modifications are feasible from the field work perspective has not been investigated; however, any steps that can be taken to modify the sequence above would be beneficial for river modelling.

Location

Work done by others (Beltaos 1979) has concluded that, during ice-covered conditions, a stream length of 66 km and 94 km is required for 95% and 98% dilution, respectively, for river bank sources. The size of the mixing zone can be reduced by 74% if the source is located at the centroid of the flow. The mixing zone also would be reduced during the open water conditions due to wind action on the water surface and turbulance from higher flows. Therefore, wherever feasible, it is recommended that the sampling stations on the Athabasca River be relocated to a significant distance downstream from any major tributaries and pollutant sources so that representative results can be obtained for modelling purposes.

Table 9 lists the sampling stations and their recommended locations. A 1 d mid-summer grab sample of the Saline Spring and Saline Lake and the estimate of flow from the spring to the Athabasca River is also recommended. This will confirm the dissolved sodium and chloride ionic strength and approximate loadings from the spring.

Table 9. Recommended water sampling locations for use in river modelling.

Station		Location
0012	Athabasca Above Horse	existing
0300	Horse	"
0040	Hangingstone	"
2300	Clearwater	"
0201	Athabasca between Clearwater and Poplar (gauged)	"
0203	Athabasca between Clearwater and Poplar	cancel
0070	Poplar	existing
0060	Steepbank	"
0204	Athabasca below Steepbank above Muskeg	just upstream of Steepbank
0205	Athabasca below Steepbank above Muskeg	cancel
0206	Athabasca below Steepbank above Muskeg	"
0080	Muskeg	existing
0011	Mackay	"
0207	Athabasca below Mackay	just upstream of Muskeg
0170	Ells	existing
0160	Joslyn	"
0208	Athabasca between Joslyn and Firebag	"
0209	Athabasca between Joslyn and Firebag	"
0010	Firebag	"
0010	Athabasca at Embarras (gauged)	"

Water Quality Parameters and Priorities

Table 10 lists a number of water quality parameters for which IEC has assigned a high, medium or low priority. Most of the parameters listed under high priority are either conservative traces of petroleum or petrochemical industry related substances which could be used as indicators of pollutant sources. Thus, the high priority parameters should be monitored at each site for the 1981 field season in accordance with the procedures outlined in Section 6.1 above.

In addition, IEC recommends the sampling of the 129 USEPA priority pollutants at typical tailings ponds to establish their possible presence and potential for seepage into the surface water system. All major peaks on the GC scan should be identified by mass spectrometry.

Parameters listed as low priority in Table 10 appear inappropriate for river modelling purposes, although Alberta Environment may wish to continue monitoring these parameters for other purposes.

Time of Travel

Time-of-travel studies for summer low flow periods appear warranted to correspond to the winter time-of-travel studies already completed. These studies would increase the credibility of existing and future water quality models developed.

Table 10. Recommended water quality parameter and priority list.

High	Medium	Low
pH	Magnesium	Specific Conductance
Dissolved oxygen	Potassium	Carbonate
Calcium	Odour & taste	Bicarbonate
Sodium[a]	Tannin & Lignin	Color
Chloride[a]	Dissolved Phosphorous	Surfact N-Alkyl
Sulphates[a]	TOC	Residue
Total Alkalinity	DOC	Turbidity
Total Hardness	Kjeldahl Nitrogen	Dissolved Sulphide
Fluoride[a]	Cadmium	Chlorophyll
Total Phosphorous	Copper	Humic Acid
Silica[a]	Iron	Fulvic Acid
Ammonia Nitrogen[a]	Lead	COD
Nitrogen, nitrate nitrite	Cynanide	Selenium
Phenolics[a]	Manganese	Barium
Oil & Grease[a]	Silver	Strontium
Hydrocarbons[a] (Alkanes)	Zinc	Coliforms
TDS[a]	Mercury	Free CO_2
PCB[a]		Titanium
Nickel		
Temperature	Aluminum	Std. Plate Count
Napthalene, Benzo Pyrene	Arsenic	TIC
Polycyctic Aromatic	Chromium	
Hydrocarbons[a]	Cobalt	
Quinoline[a]	Boron	
Vanadium		
	Antimony	
	Phthalates	
	Hexachlorobenzene[a]	
	Beryllium	
	Molybdenum	
	BOD	

[a]Petroleum/Petrochemical Industry Related Substances that may become important in the future.

7. FUTURE MODEL CAPABILITIES

Phase II of the proposed research, if approved by Alberta Environment, would complete the calibration of the mass balance model for chloride, sodium, alkalinity, and hardness by use of more sophisticated statistical analysis than possible in Phase I. The 1980 field data would be incorporated and once the model is calibrated and tested for inorganics, other parameters of interest to Alberta Environment could be examined. These parameters may include organic compounds, and industrial and municipal effluent related substances. The final recommended scope for Phase II will be outlined in a separate document. It is expected that Phase II would result in a basic river model and understanding of the Athabasca water quality mechanisms. Overall watershed management by Alberta Environment then could be possible by use of this basic model.

7.1 REQUIRED MODEL INPUT

After completion of Phase II, the resulting Athabasca River assimilative model would represent a baseline model for the 1976 to 1980/81 period. Projected municipal and industrial development in the 1980's may result in significant impact on the existing water quality in the Athabasca watershed area. These changes, in terms of water consumption, effluent discharge, and additional waste loading on the Athabasca watershed, will have to be assessed and superimposed on the baseline model. The future model would incorporate these projected inputs and provide quantified future impacts.

7.2 EXPECTED MODEL OUTPUT

Once calibrated and tested, the river model would predict mass loading or concentration of a parameter at any point along the study area for different development scenarios. Conversely, the model could estimate the input that would be required to produce detectable changes. Watershed management administrators then may make use of this model to evaluate the impact of future oil sands development along the Athabasca River.

For example, it may be necessary to address the impact of dissolved chloride concentration on Athabasca water quality from the discharge of a proposed heavy oil plant to start up in 1989. Since both the waste water characteristics from the plant and the baseline chloride concentration of the Athabasca River would be known, it would be possible by the application of the river model to estimate for a 1 in 10 yr minimum flow condition what the chloride concentration would be 60 km downstream of the plant. Other develoment scenarios could be investigated and results generated to select the option in watershed management plans. Alberta Environment then would have the capability of establishing the terms and conditions for approval of future development projects in the Athabasca River watershed.

8. CONCLUSIONS

1. Based on a preliminary manual mass balance model, it was possible to account for essentially all the Athabasca River flow, alkalinity, and hardness at Embarras from the existing surface water sources monitored by Alberta Environment. As a result, it appears that there is no major flow or mass loading of these parameters originating from ground water entering or leaving the Athabasca River.

2. The mass balance model was not able to account for dissolved sodium or chloride mass loading at Embarras from existing surface water monitoring stations. Tentatively, it has been concluded that there is a significant mass input of concentrated sodium and chloride ions not presently monitored. There are indications that the Saline Spring just downstream from the confluence of the Steepbank and Athabasca rivers may have contributed significant amounts of sodium and chloride ions.

3. It appears possible now to investigate transformations, impacts, and assimilation of non-conservative substances in the Athabasca River utilizing the mass balance concepts developed for conservative substances in the study. The resulting evaluations of various development scenarios will allow comprehensive management planning to be completed for the Athabasca watershed.

9. REFERENCES CITED

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Water Management, Goals, Policies, Objectives and Implementation Procedures of the Ontario Ministry of the Environment. November, 1978. 67 pp.

10. APPENDIX

10.1 FIGURES 7 THROUGH 70: PLOTS OF MEASURED FLOW (m^3/s) VERSUS MEASURED CONCENTRATION (m/L).

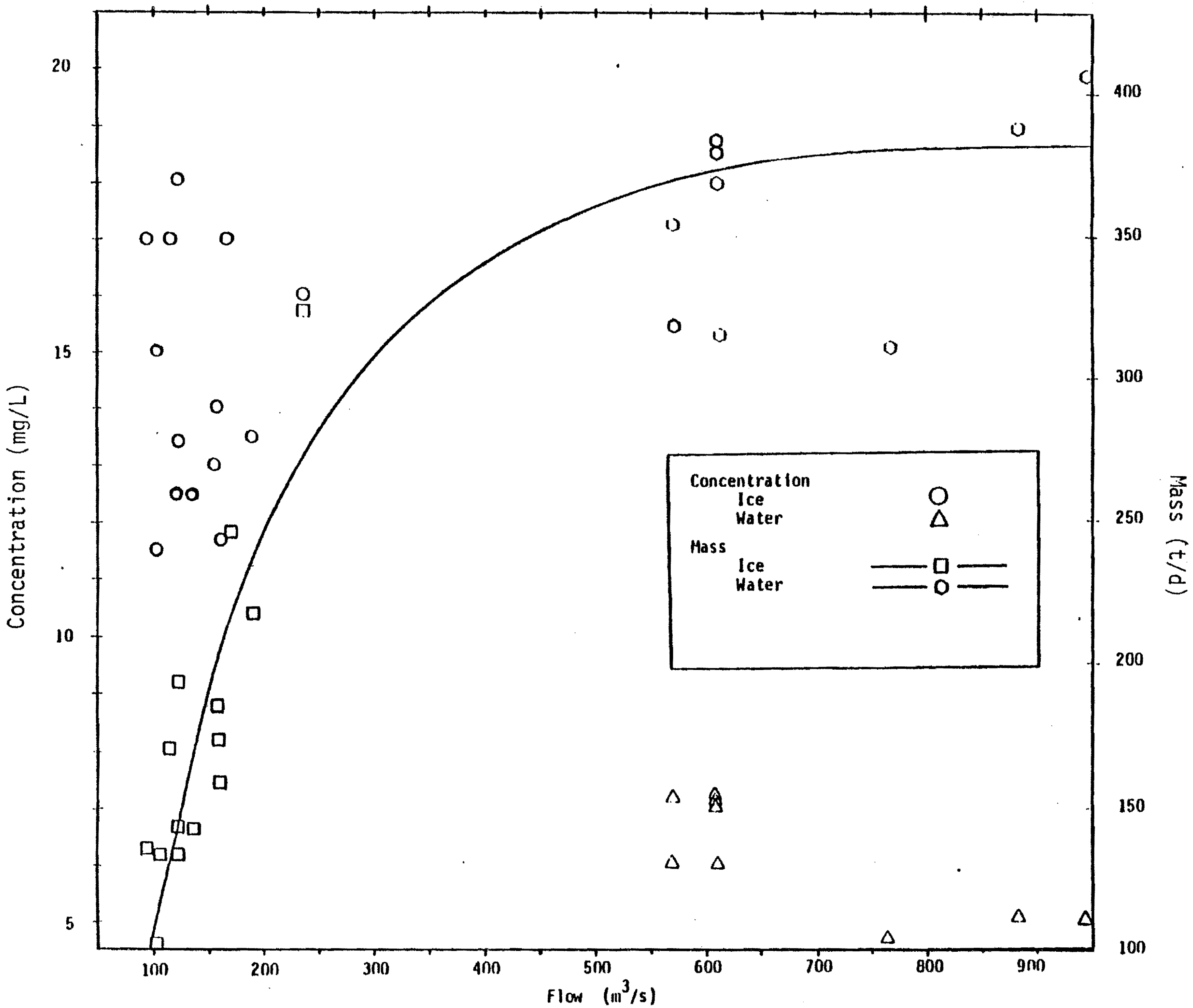


Figure 7. Dissolved sodium vs. flow: Athabasca River above Horse River.

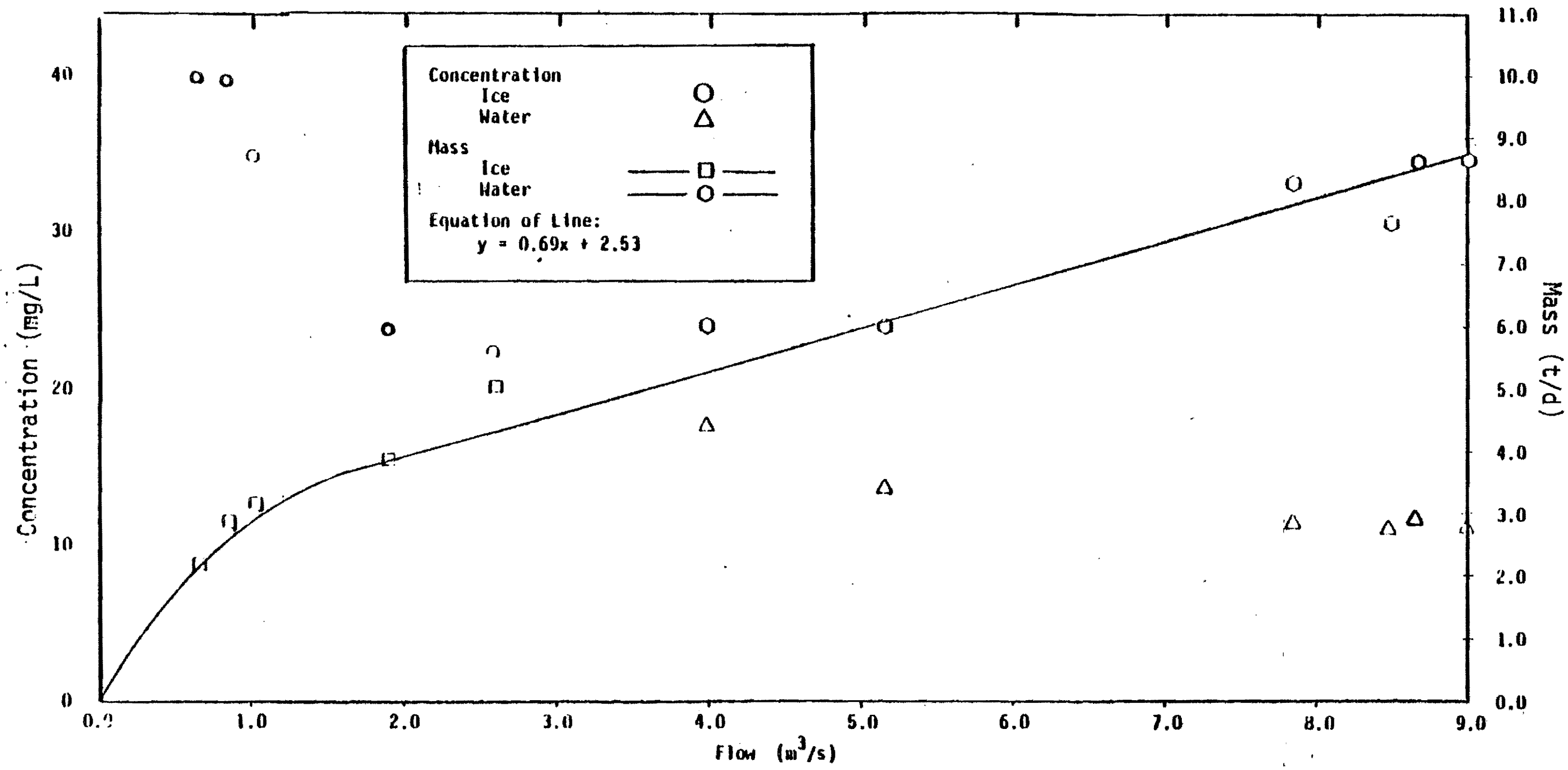


Figure 8. Dissolved sodium vs. flow: Horse River.

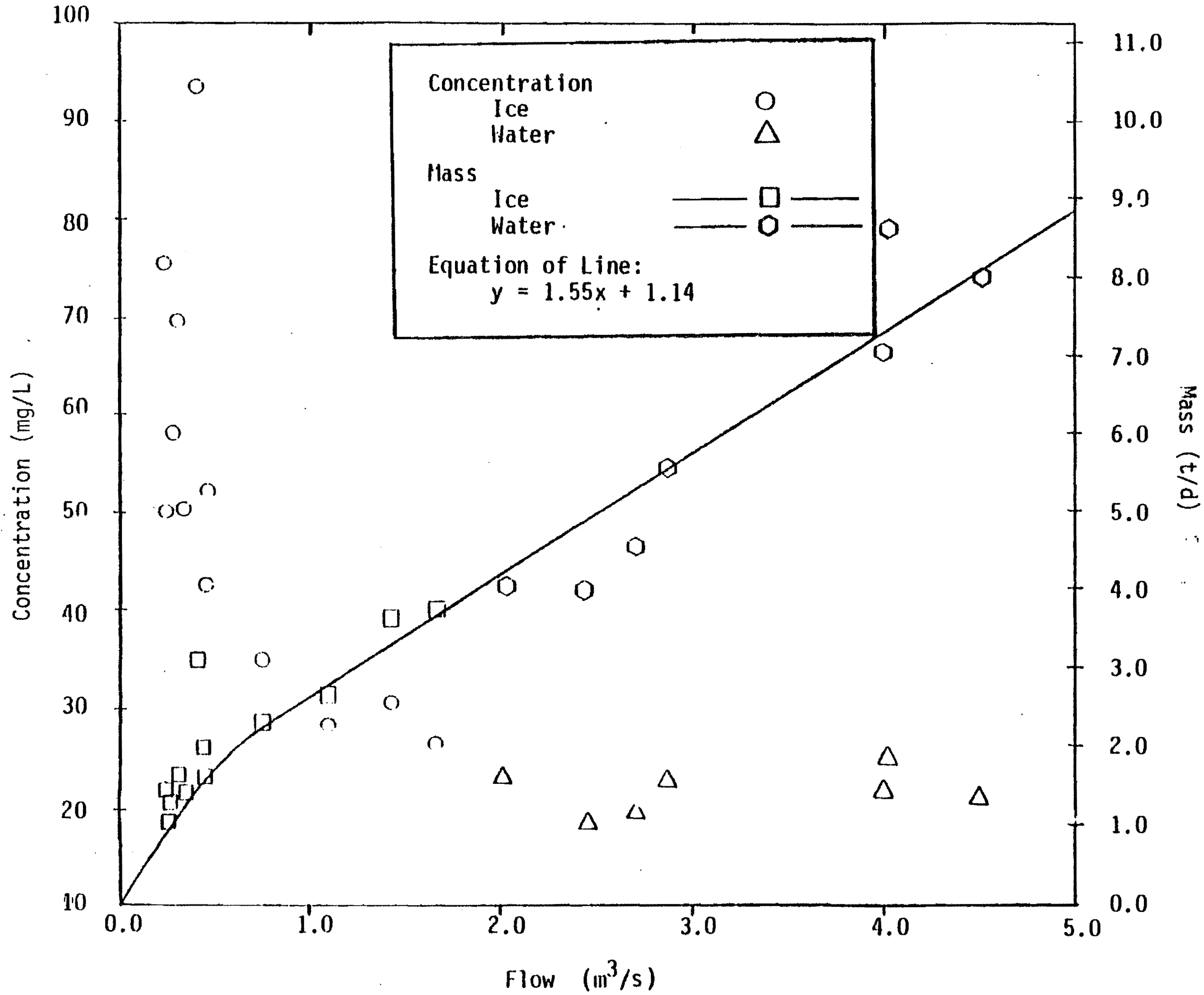


Figure 9. Dissolved sodium vs. flow: Hangingstone River.

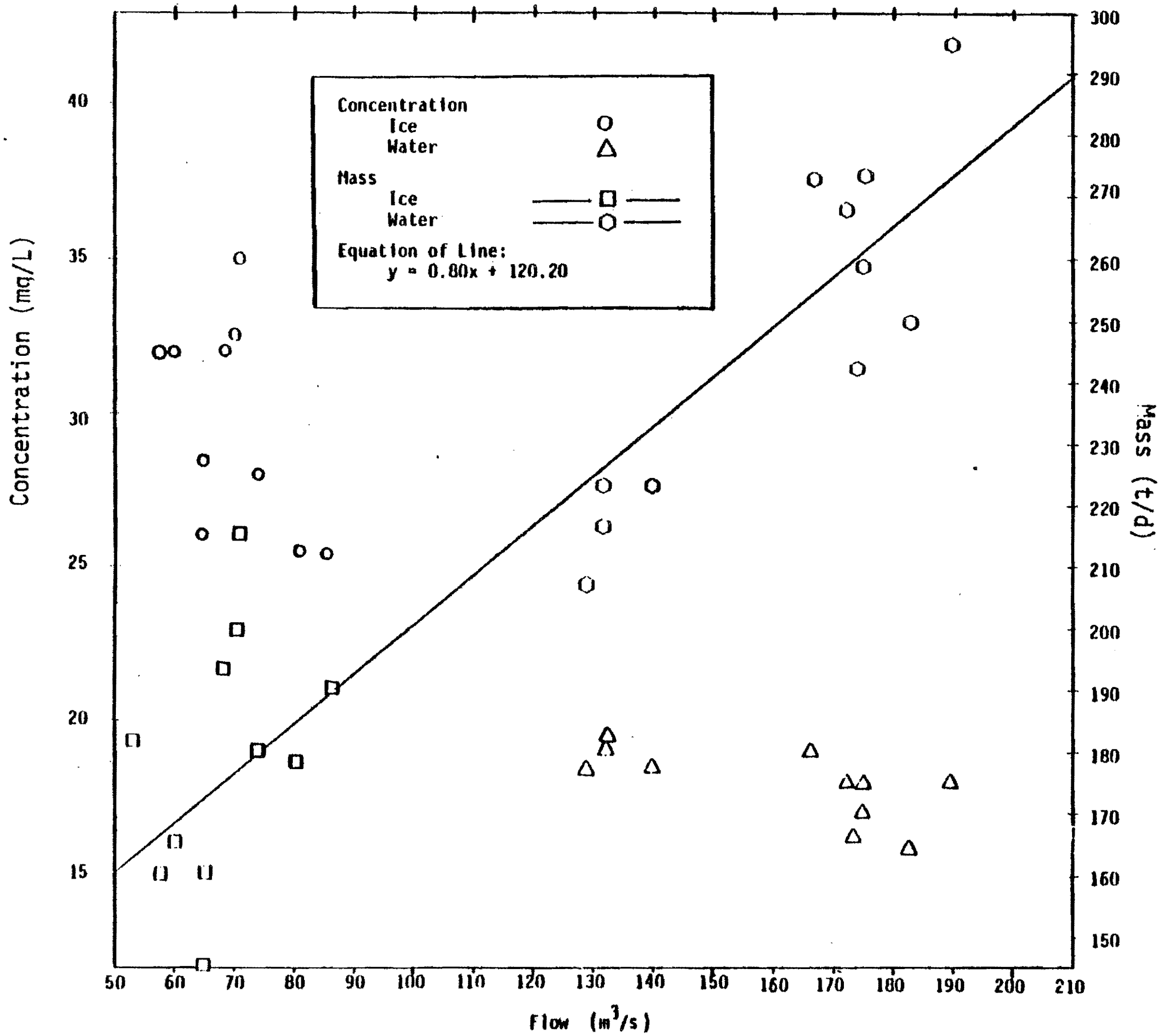


Figure 10. Dissolved soidum vs. flow: Clearwater River.

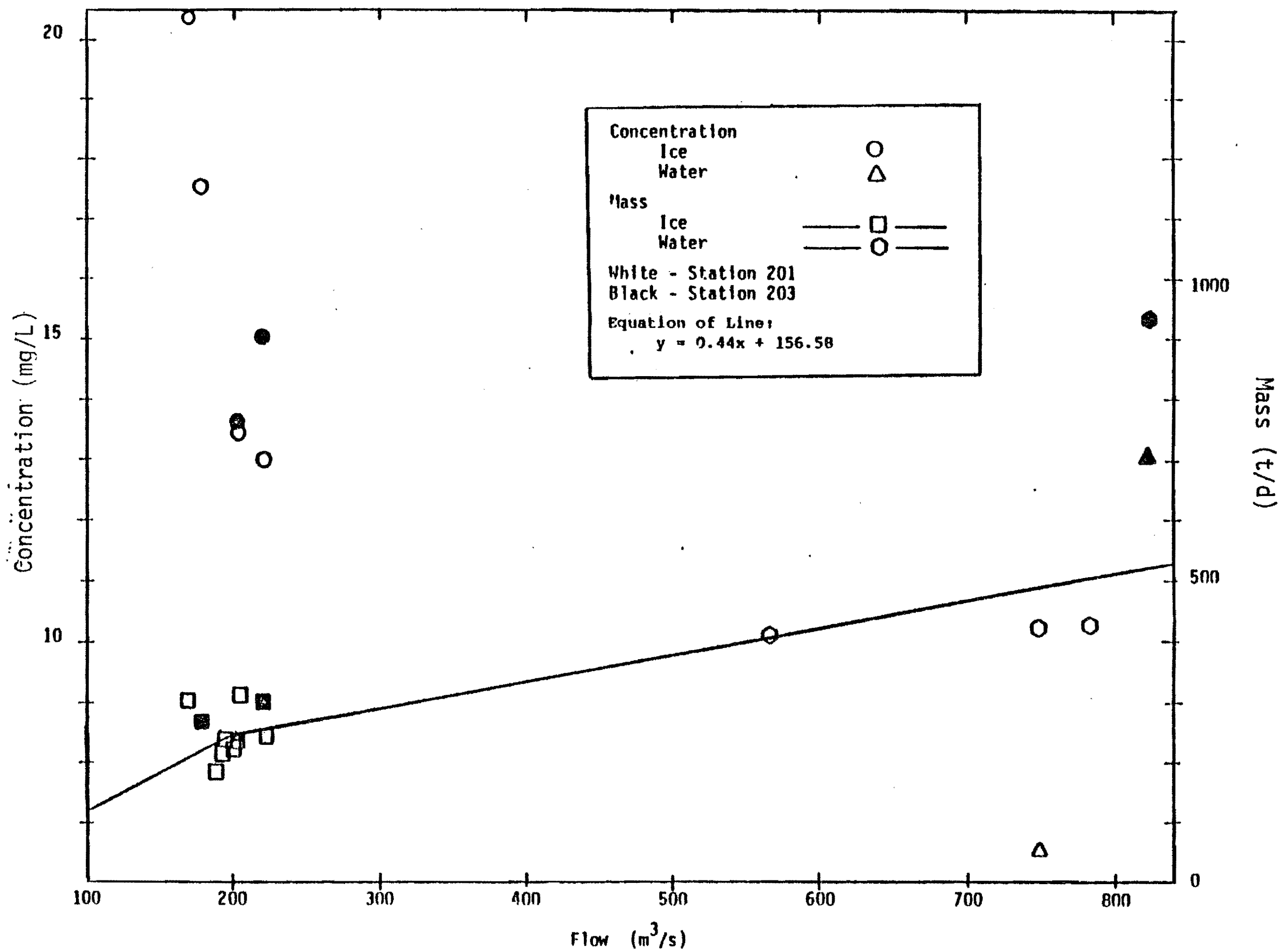


Figure 11. Dissolved sodium vs. flow: Athabasca River between Clearwater River and Poplar Creek.

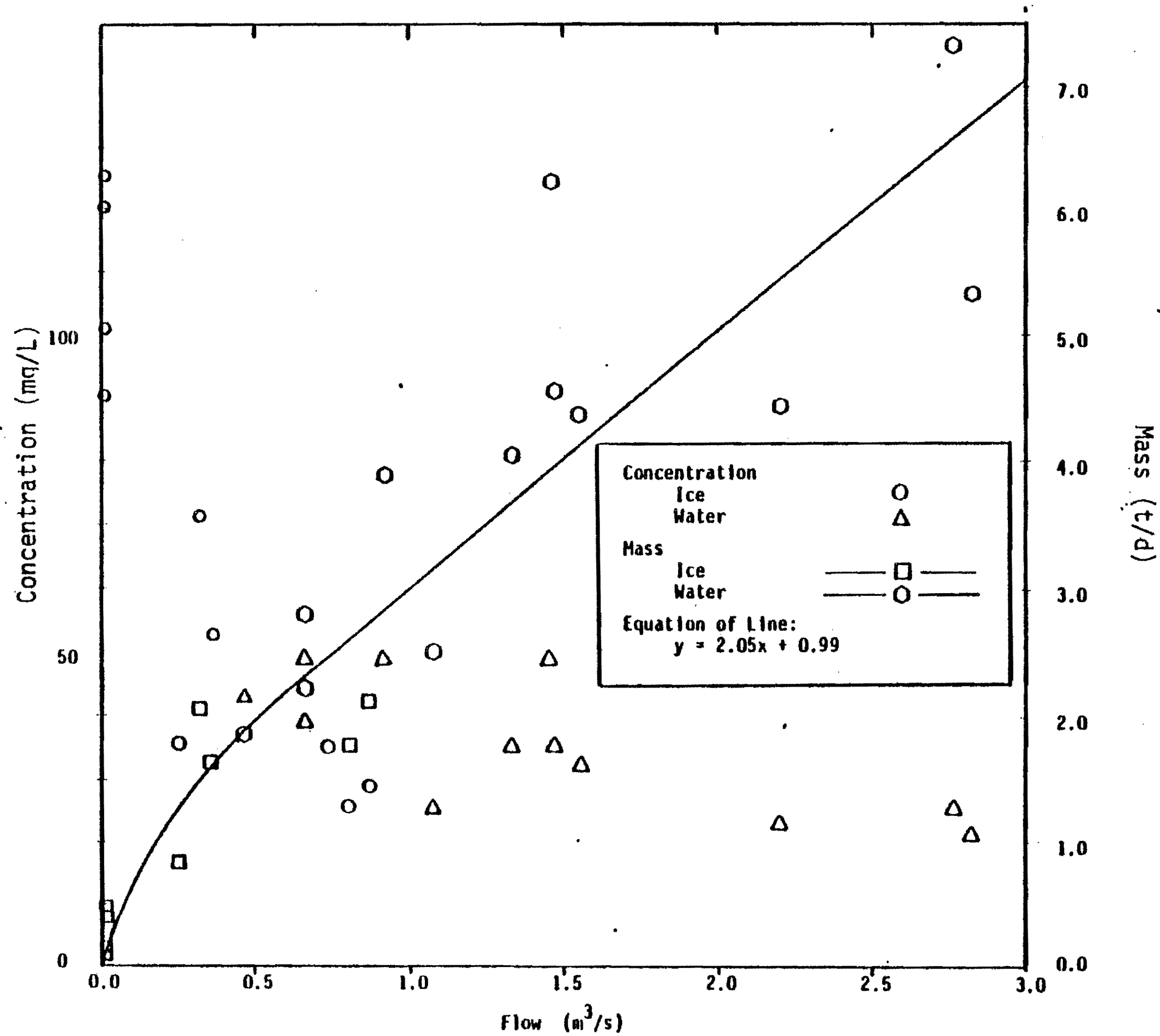


Figure 12. Dissolved sodium vs. flow: Poplar Creek.

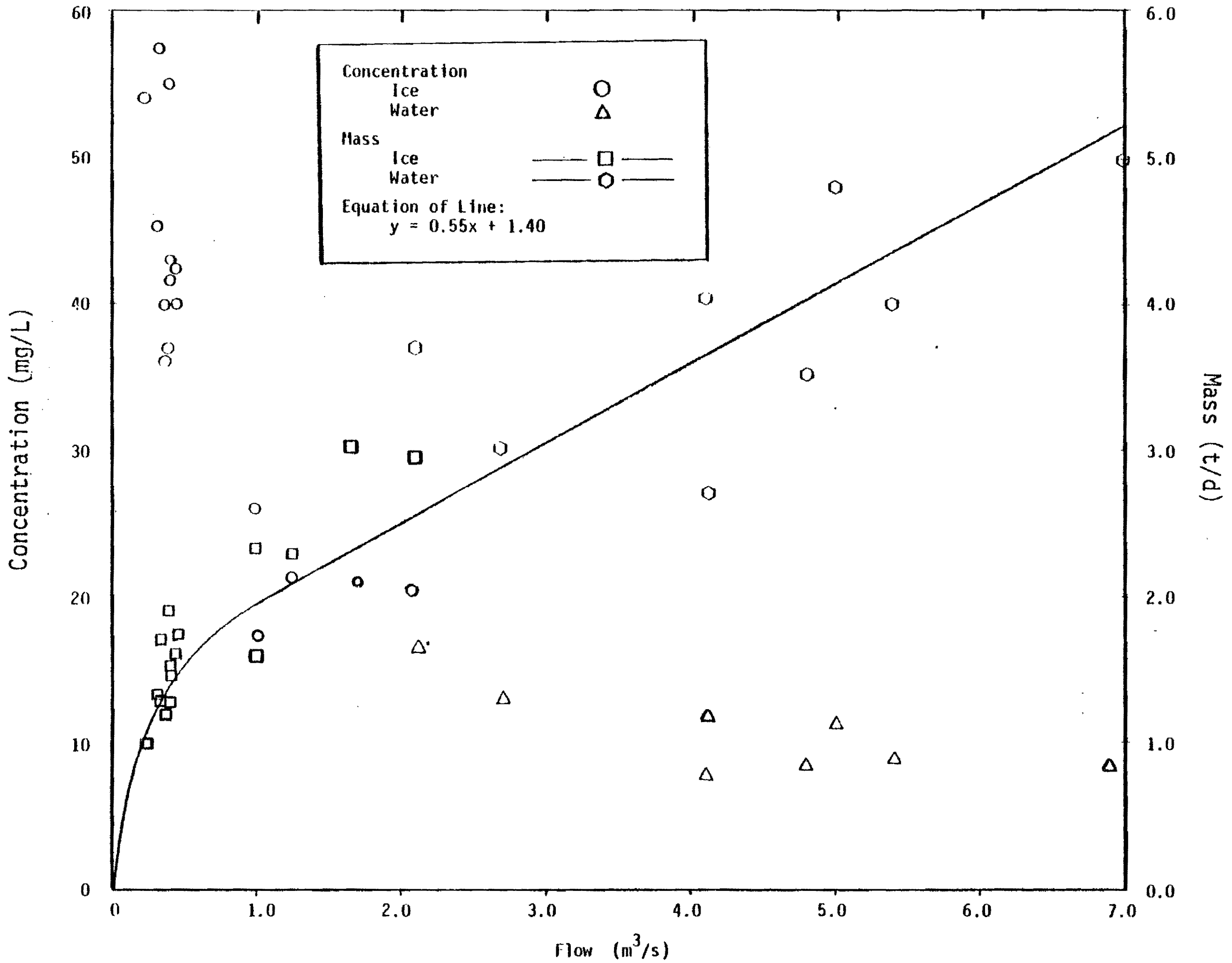


Figure 13. Dissolved sodium vs. flow: Steenbank River.

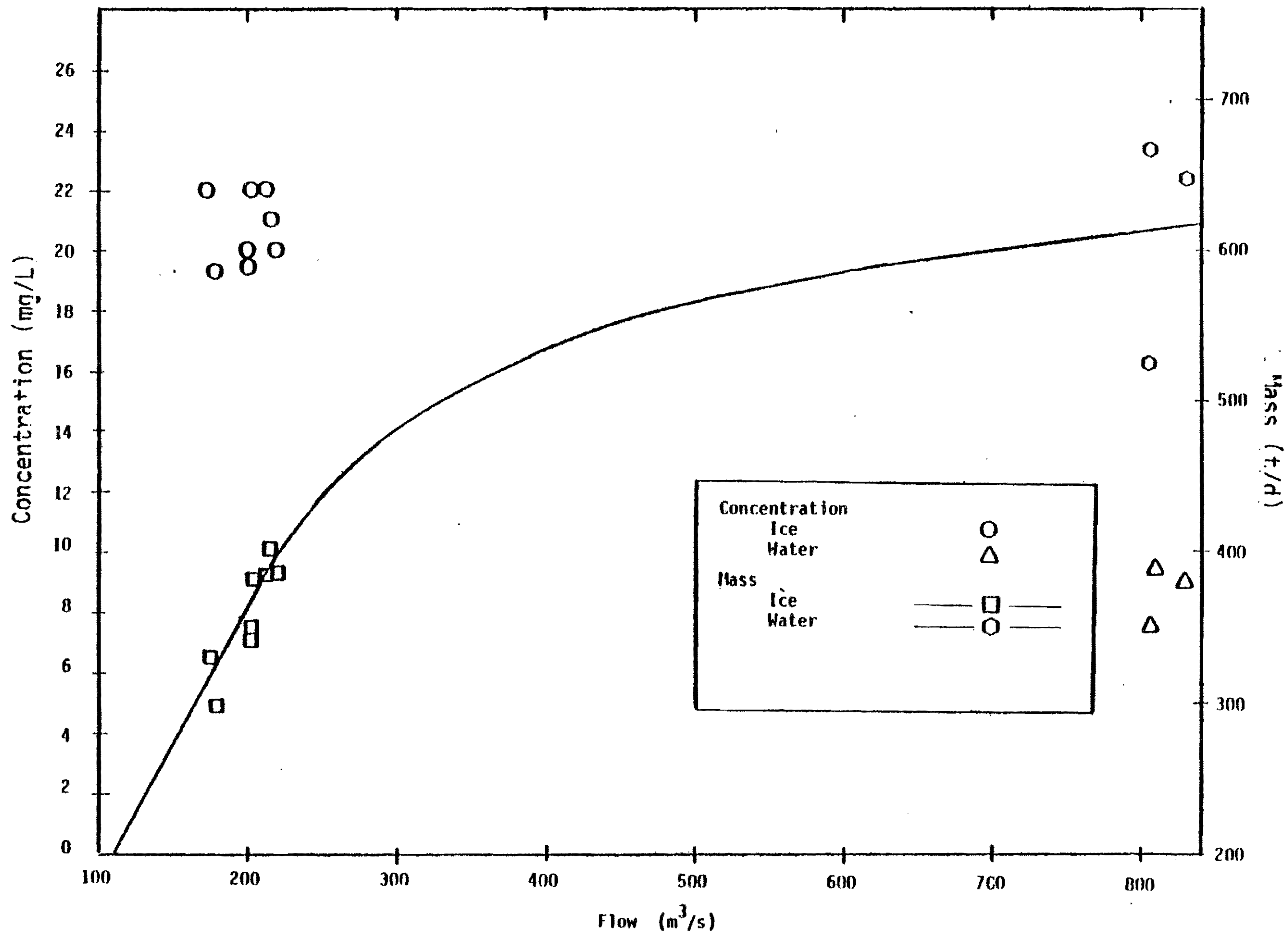


Figure 14. Dissolved sodium vs. flow: Athabasca River between the Steepbank and Muskeg Rivers.

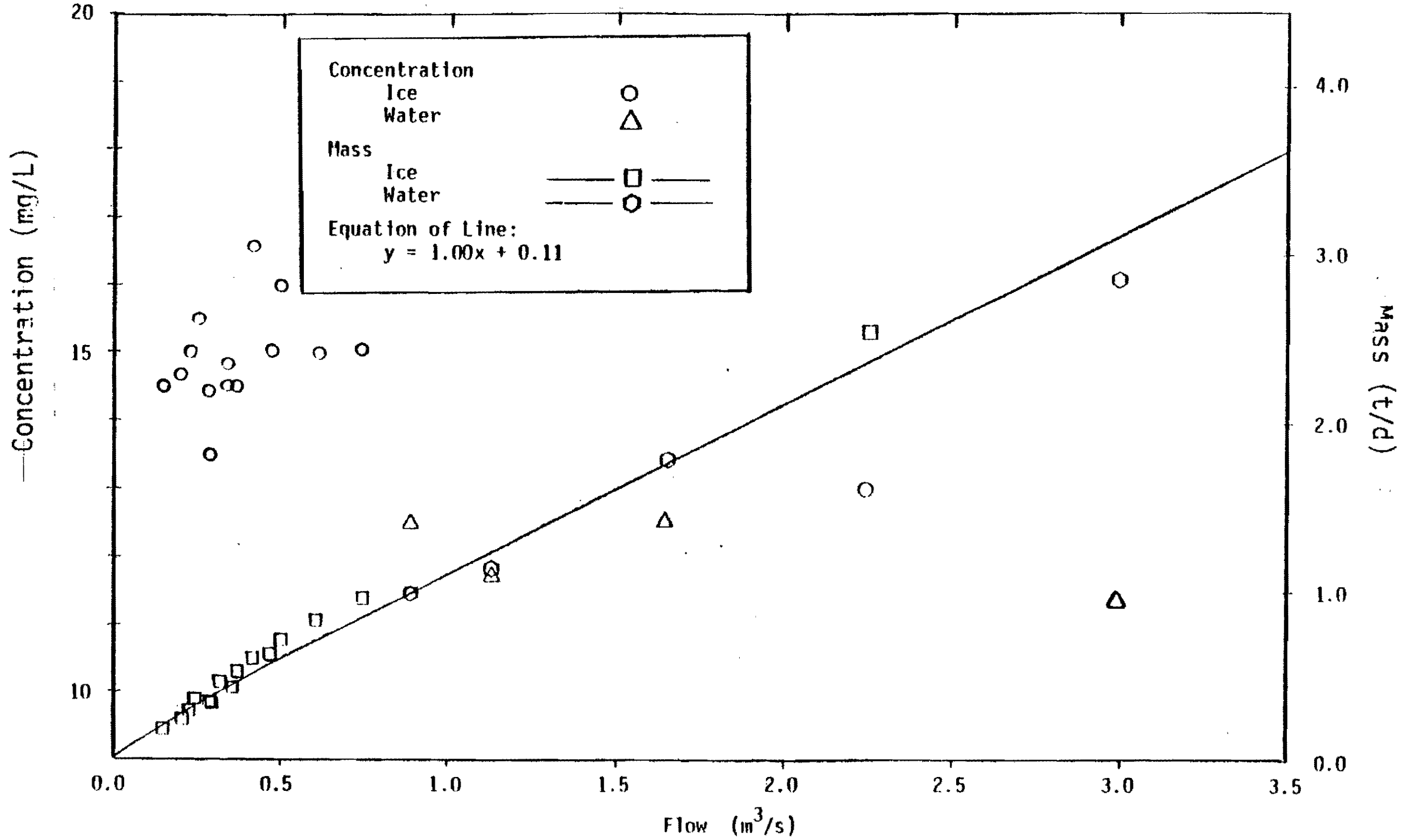
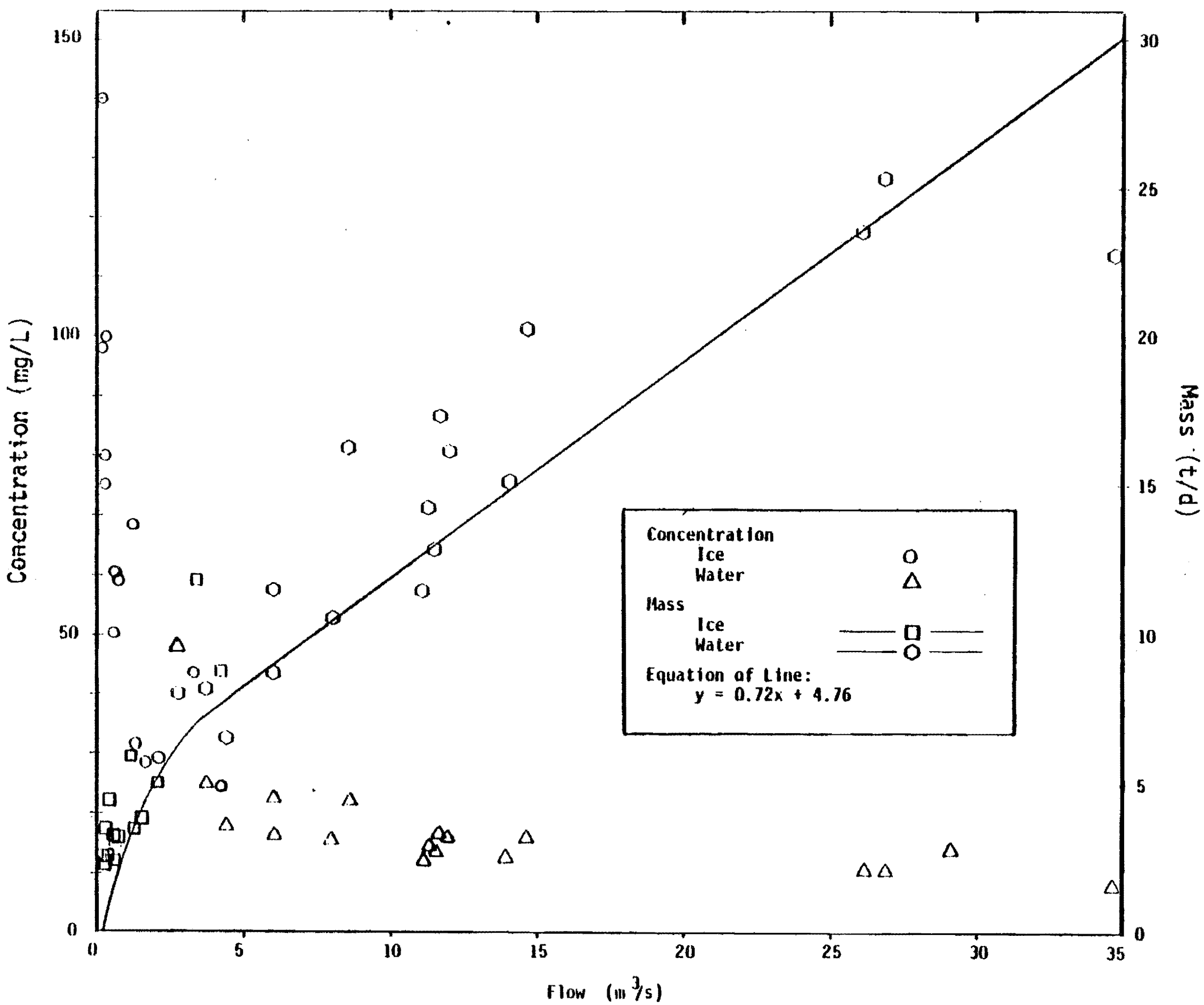


Figure 15. Dissolved sodium vs. flow: Muskeg River.



Fiqure 16. Dissolved sodium vs. flow: Mackay I

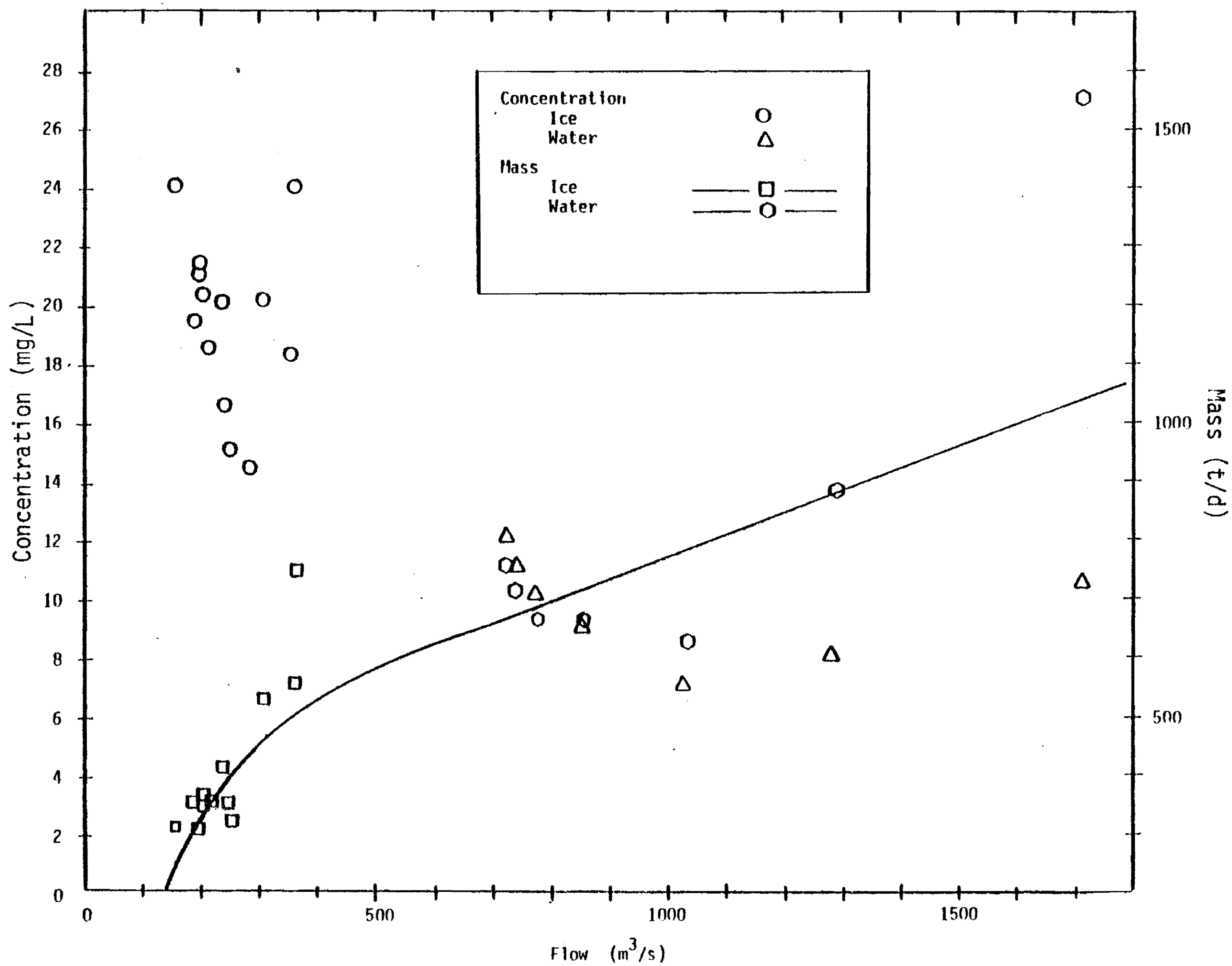


Figure 17. Dissolved sodium vs. flow: Athabasca River below Mackay River.

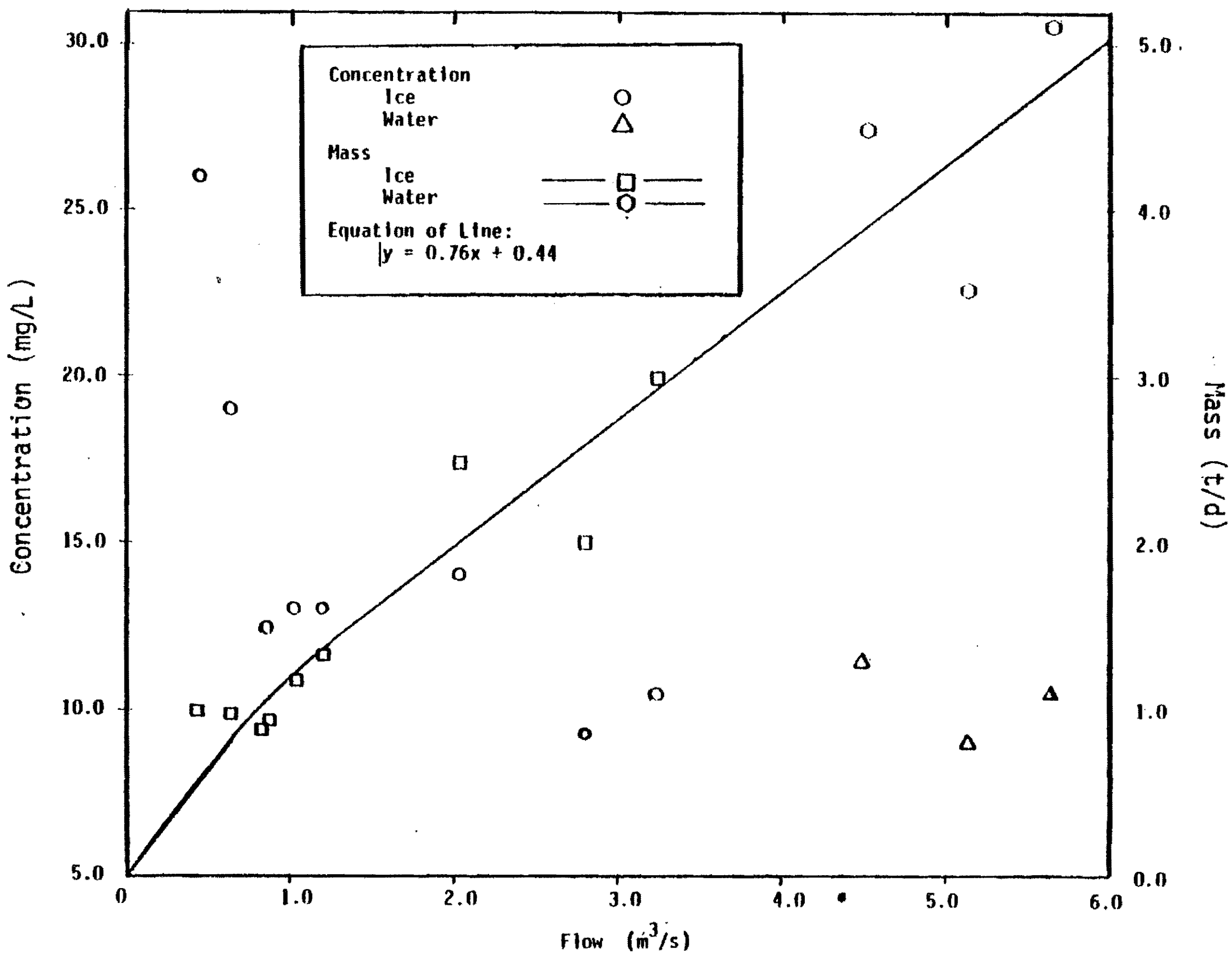


Figure 18. Dissolved sodium vs. flow: Ells River.

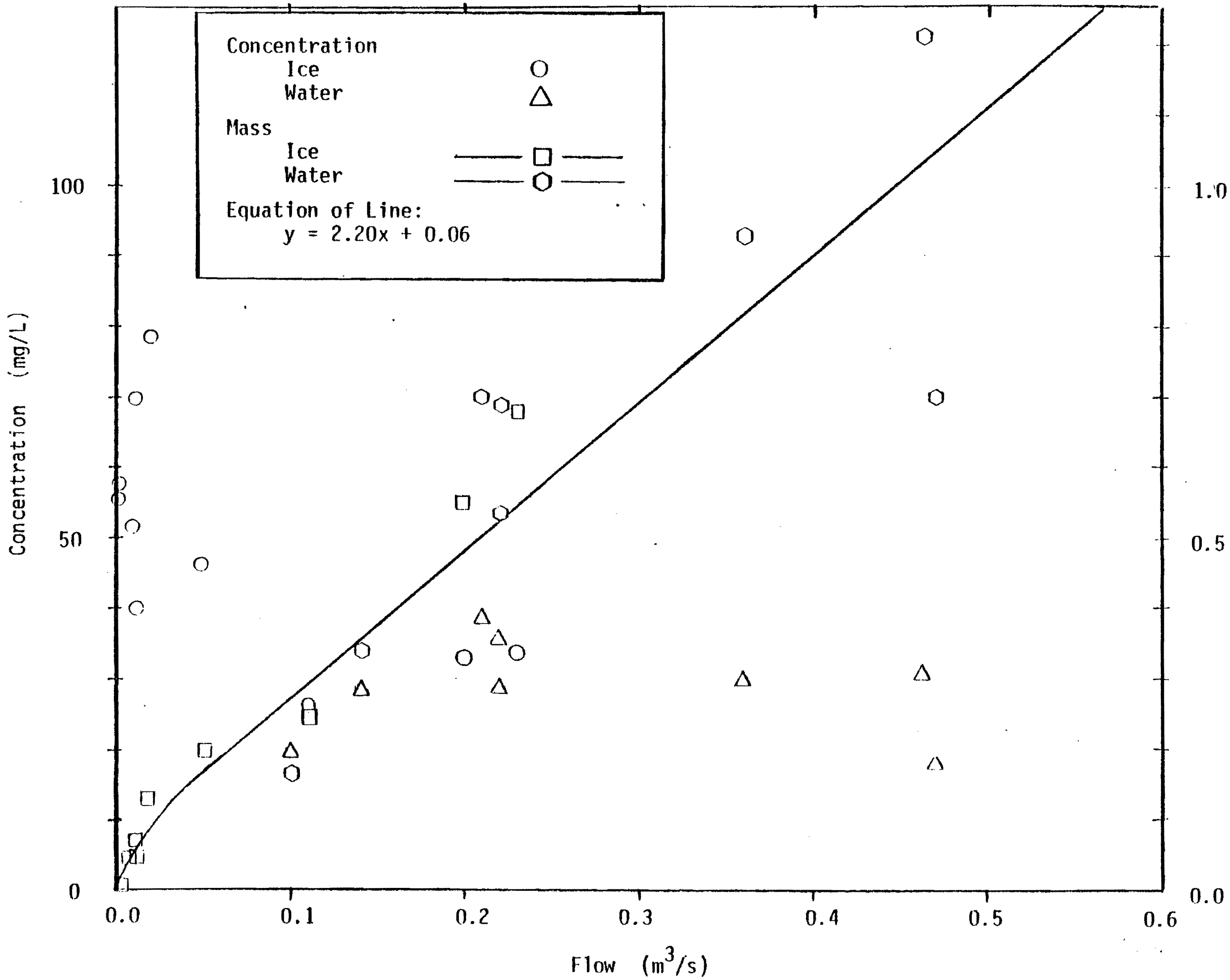


Figure 19. Dissolved sodium vs. flow: Joslyn Creek.

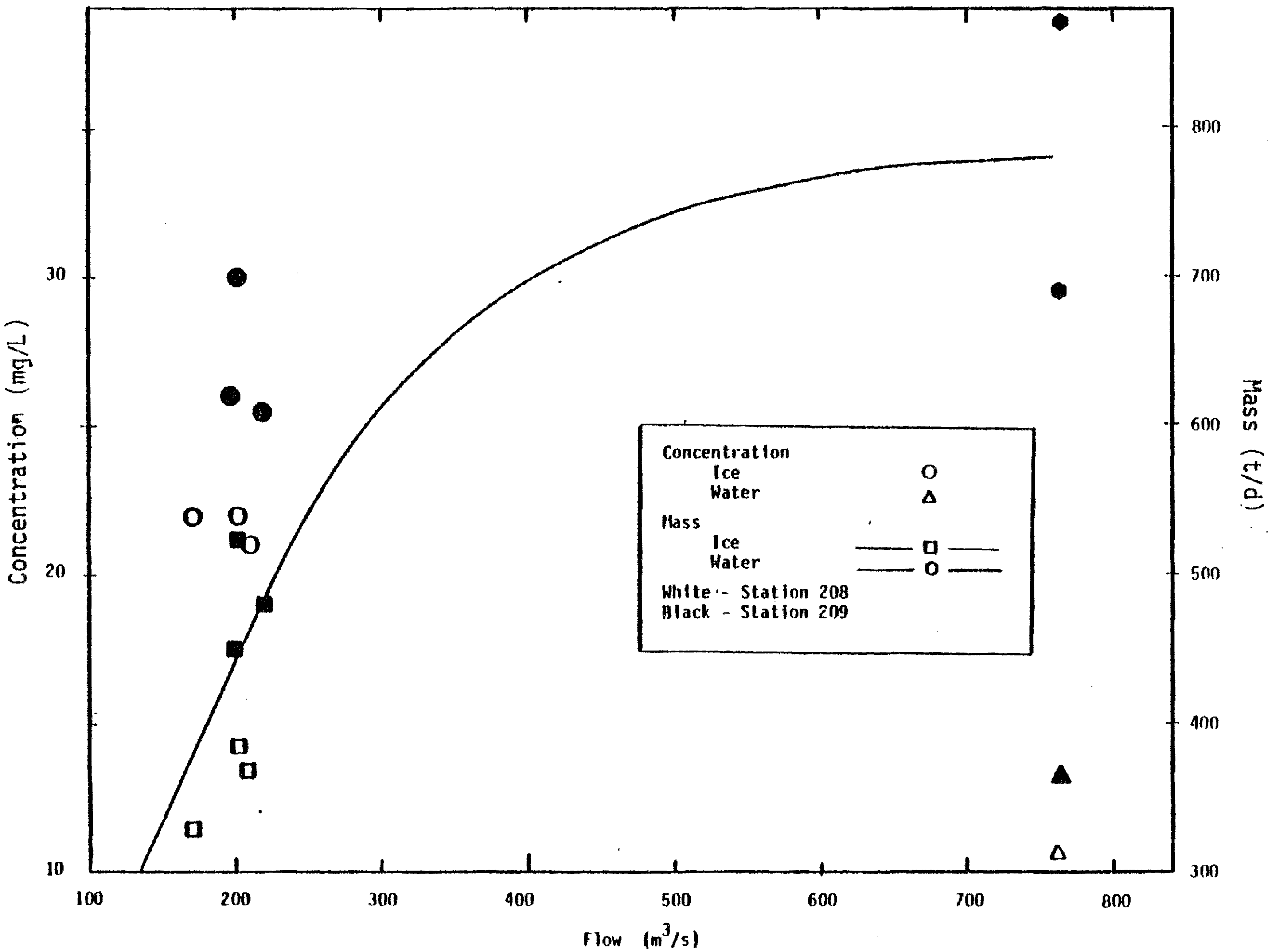


Figure 20. Dissolved sodium vs. flow: Athabasca River between Joslyn Creek and Firebag River.

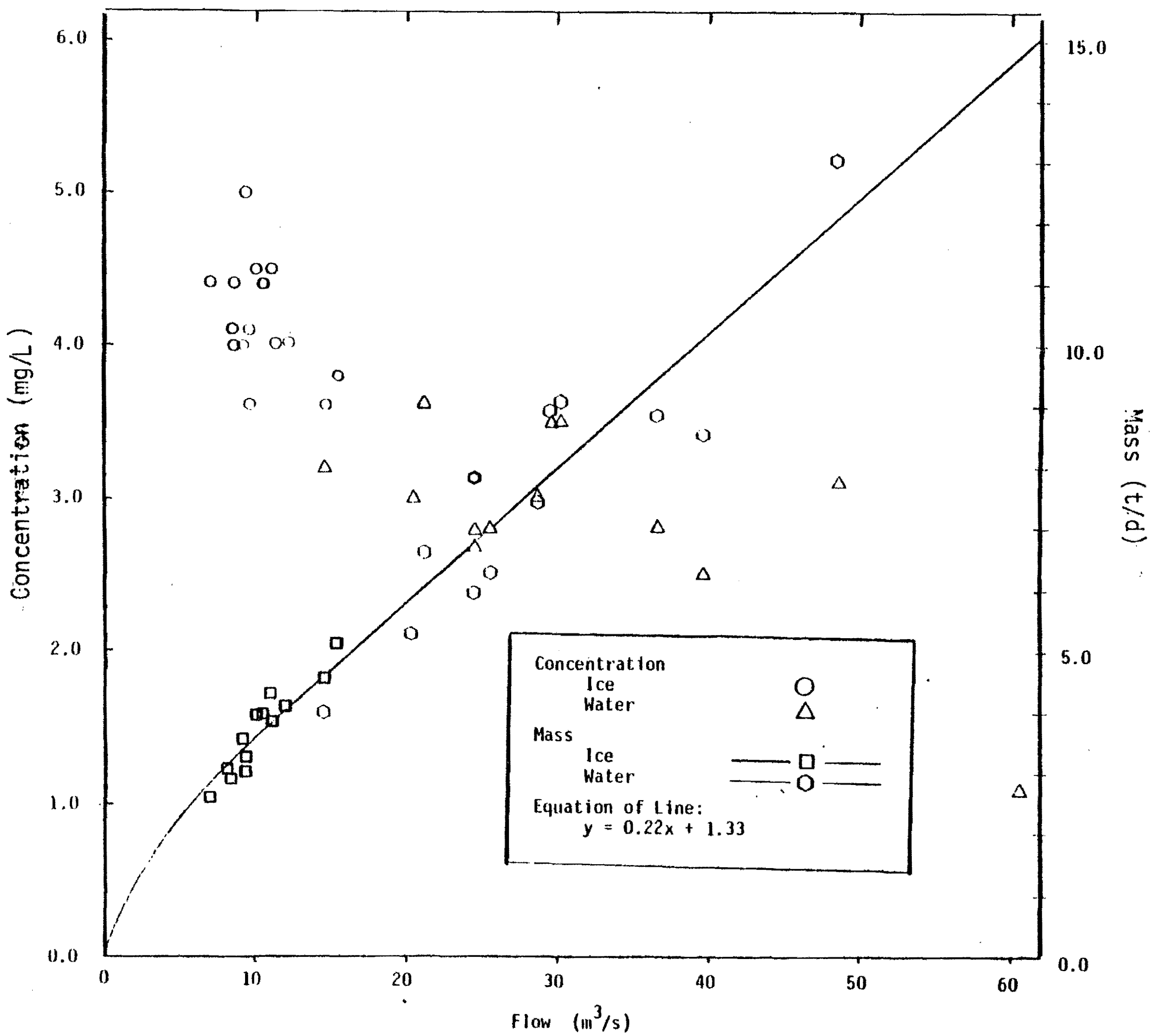


Figure 21. Dissolved sodium vs. flow: Firebag River.

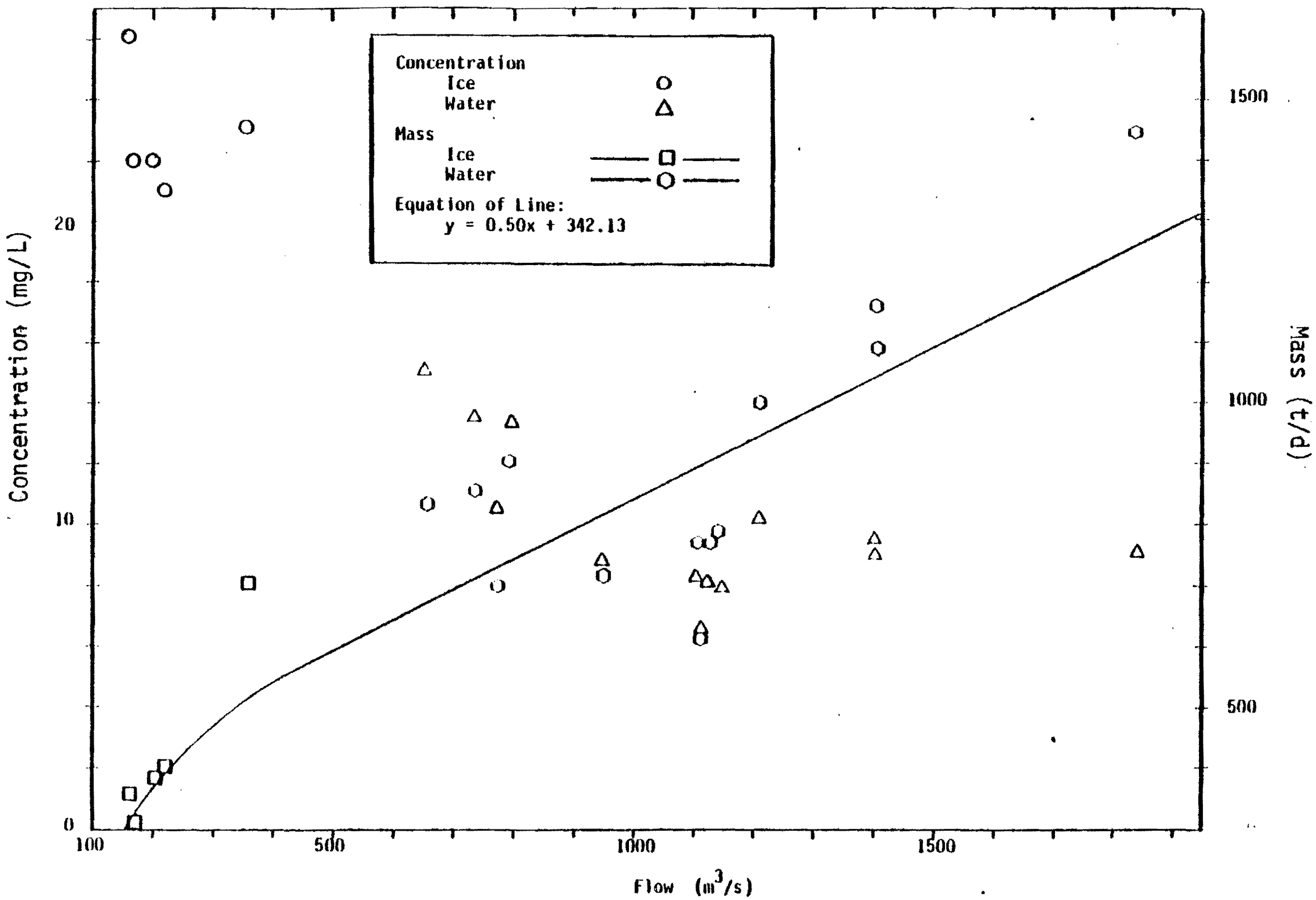


Figure 22. Dissolved sodium vs. flow: Athabasca River at Embarras.

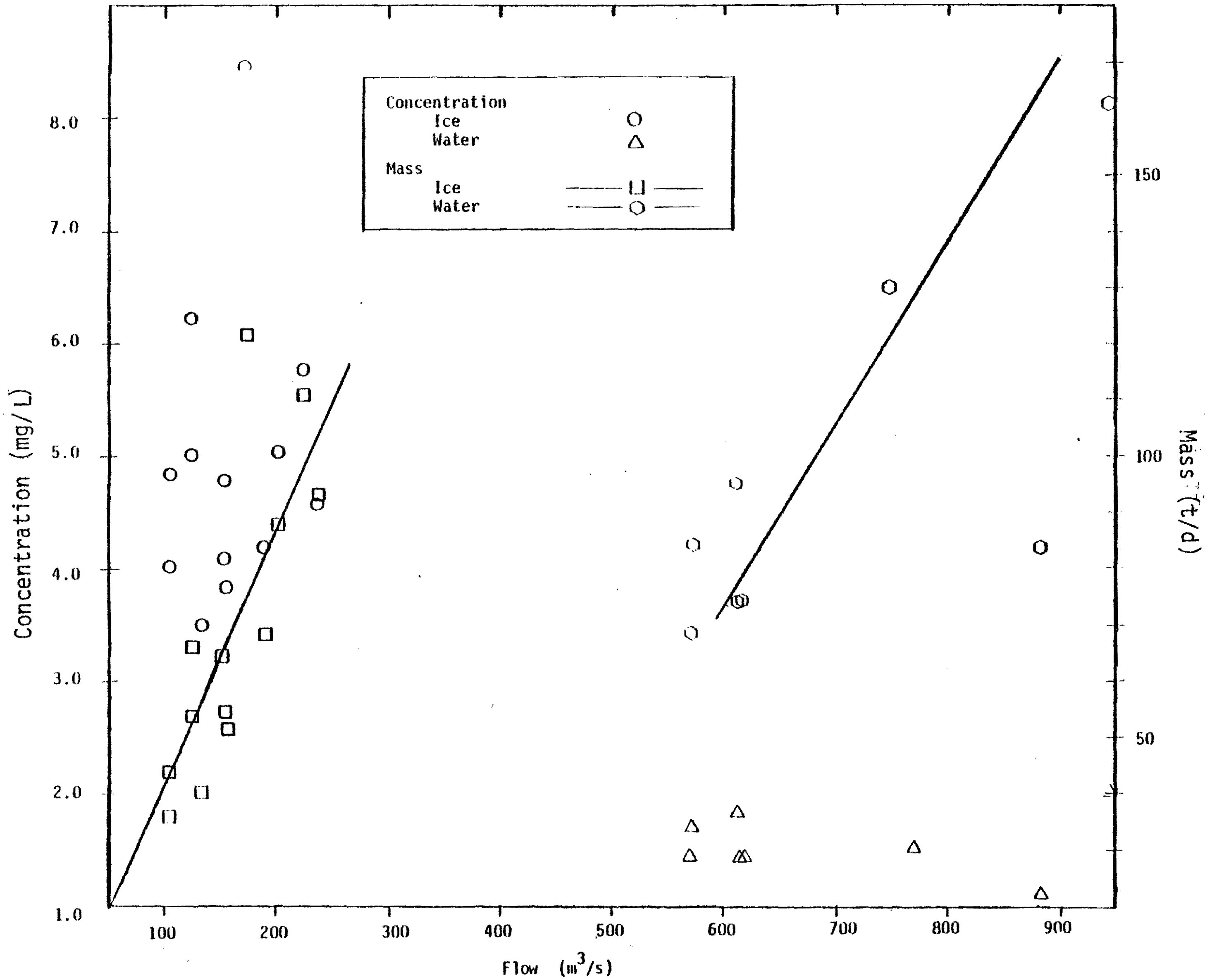


Figure 23. Dissolved chloride vs. flow: Athabasca River above Horse River.

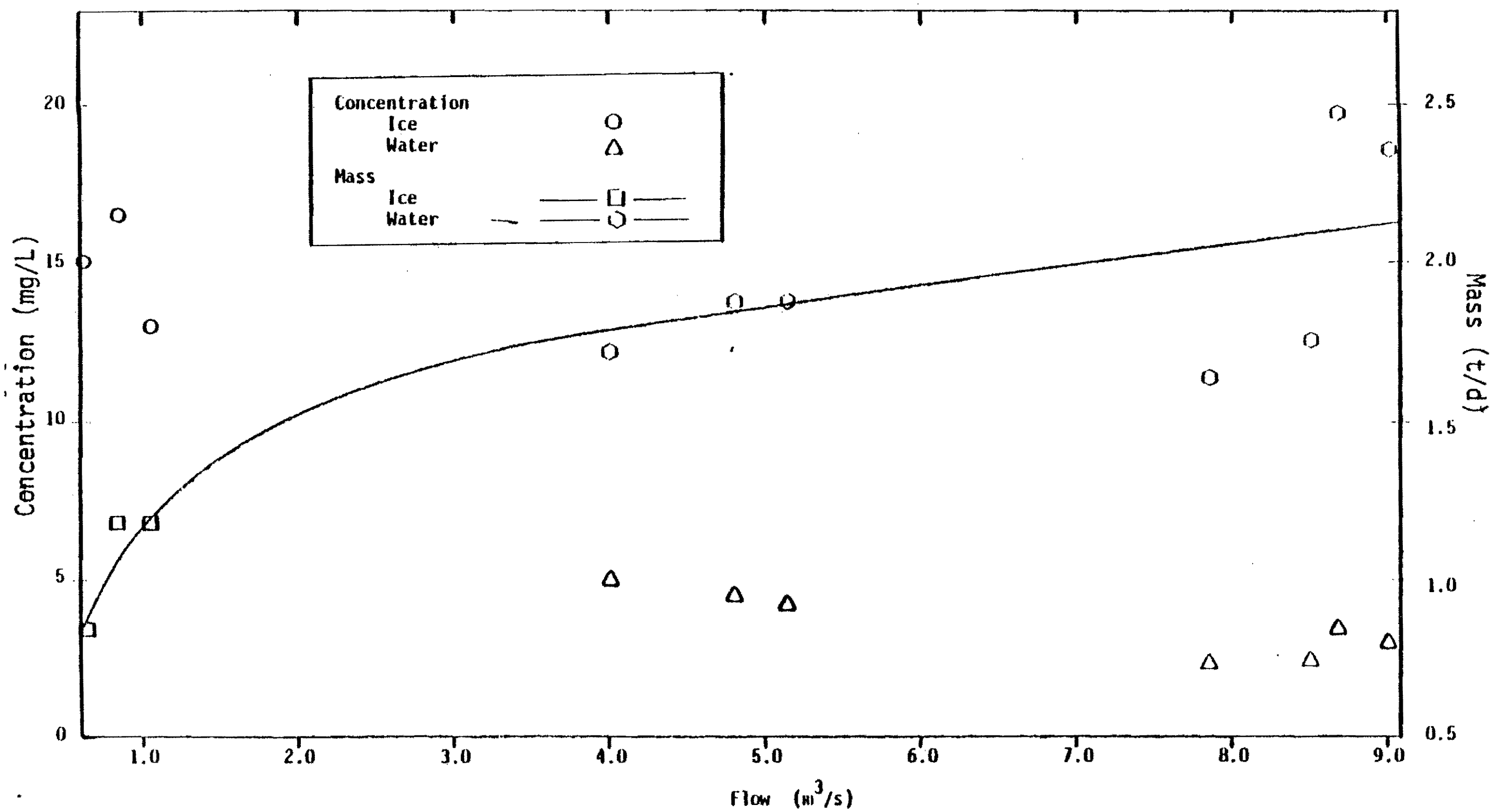


Figure 24. Dissolved chloride vs. flow: Horse River.

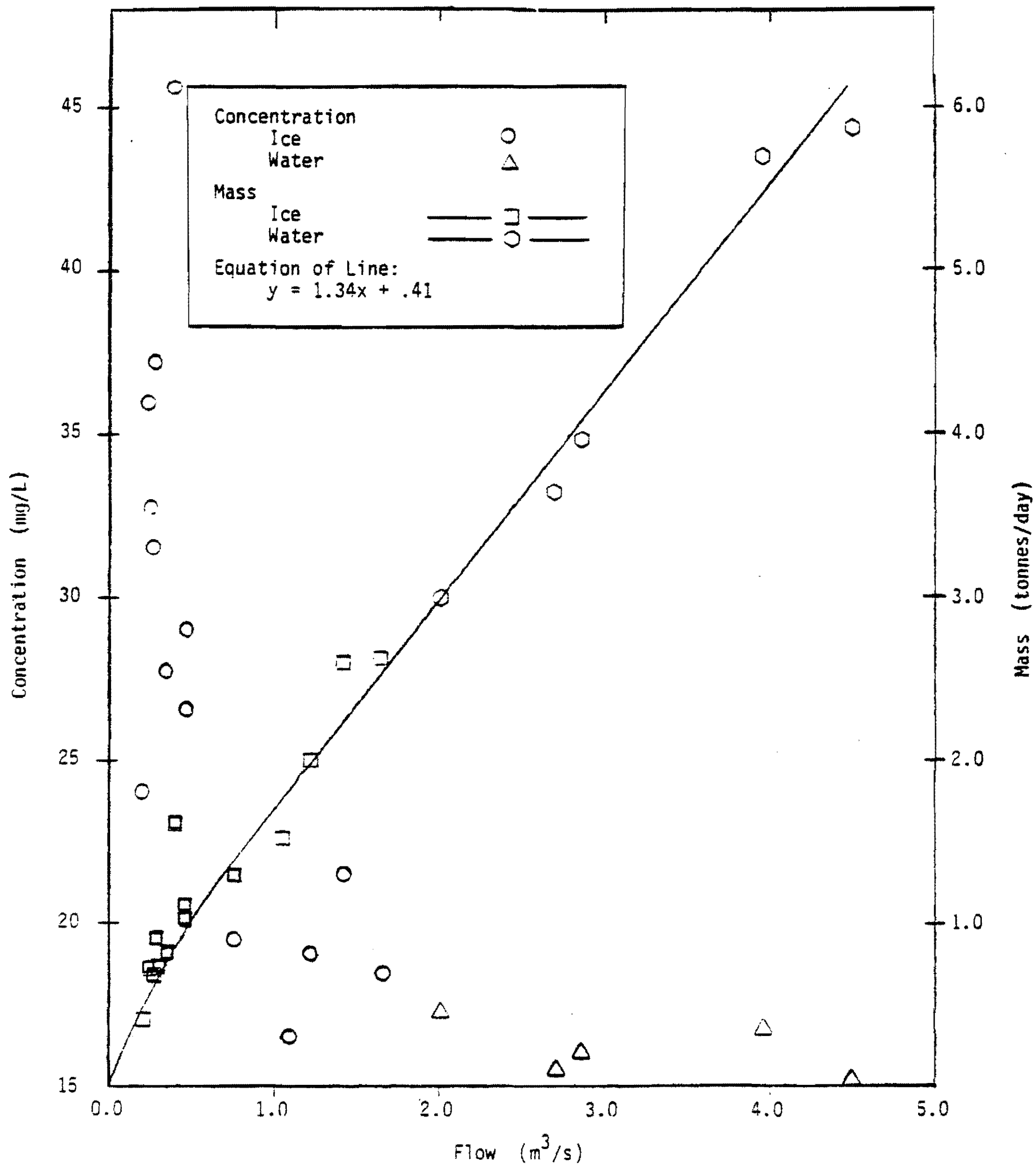


Figure 25. Dissolved chloride vs. flow: Hangingstone River.

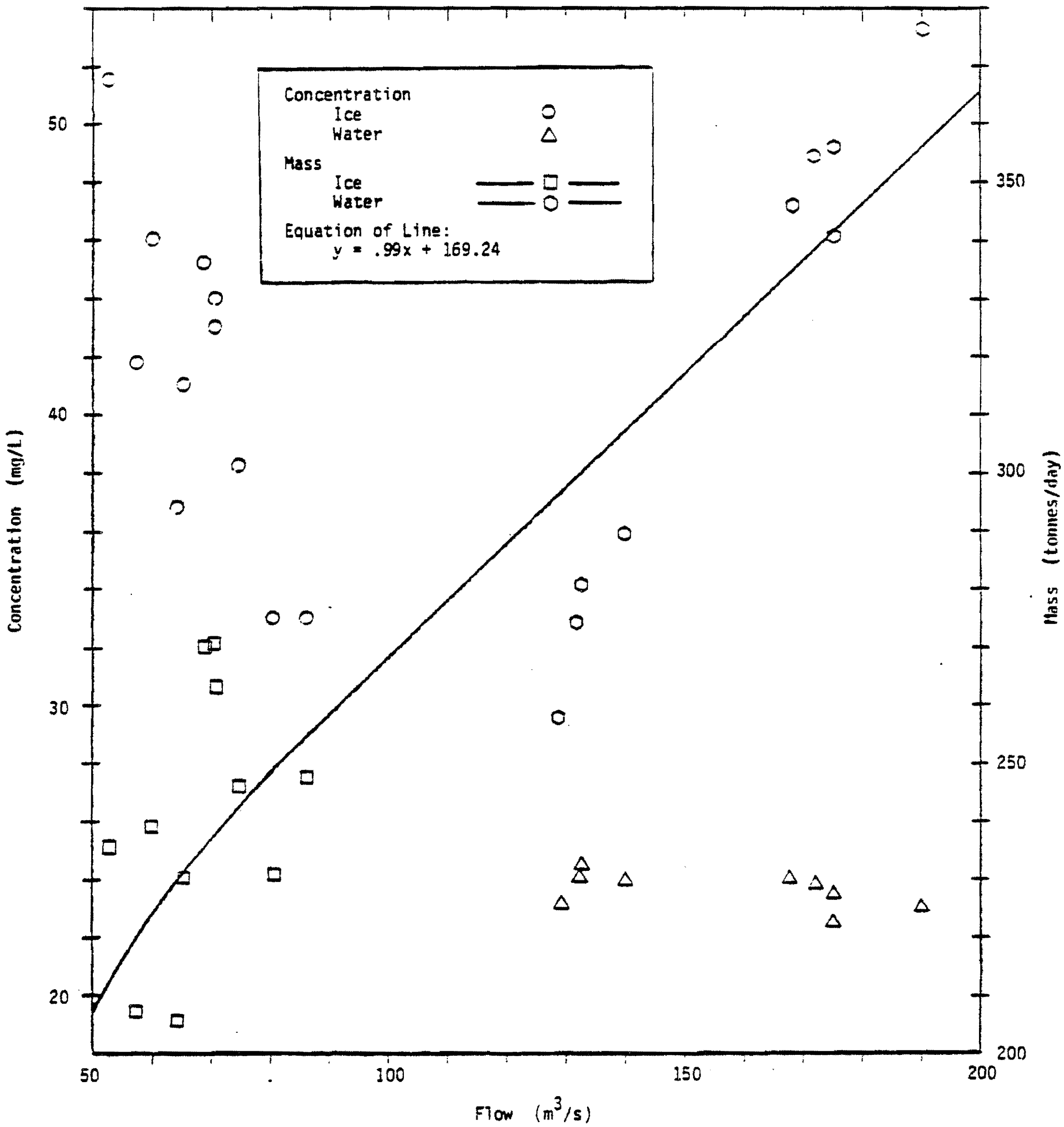


Figure 26. Dissolved chloride vs. flow: Clearwater River.

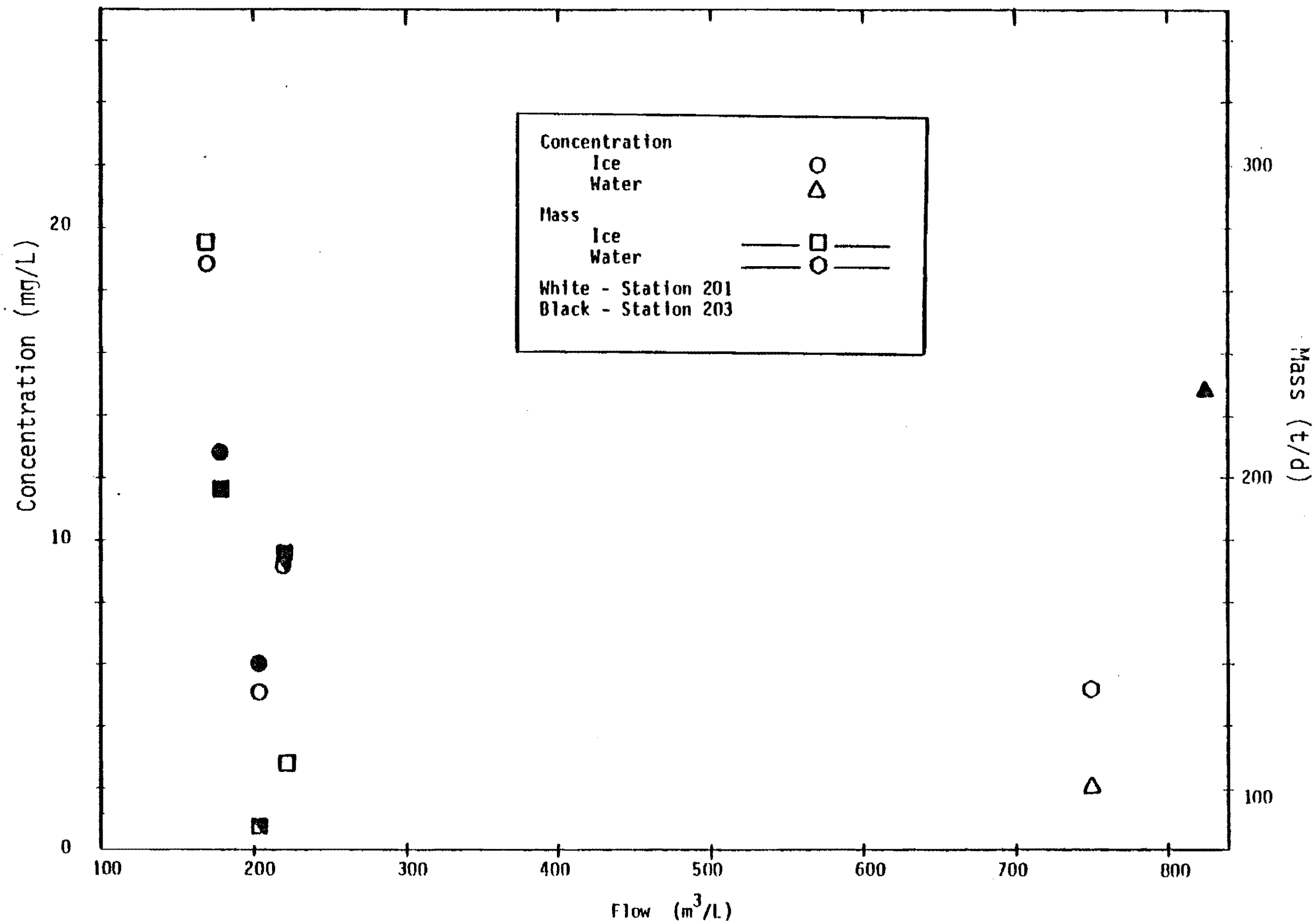


Figure 27. Dissolved chloride vs. flow: Athabasca River between Clearwater River and Poplar Creek.

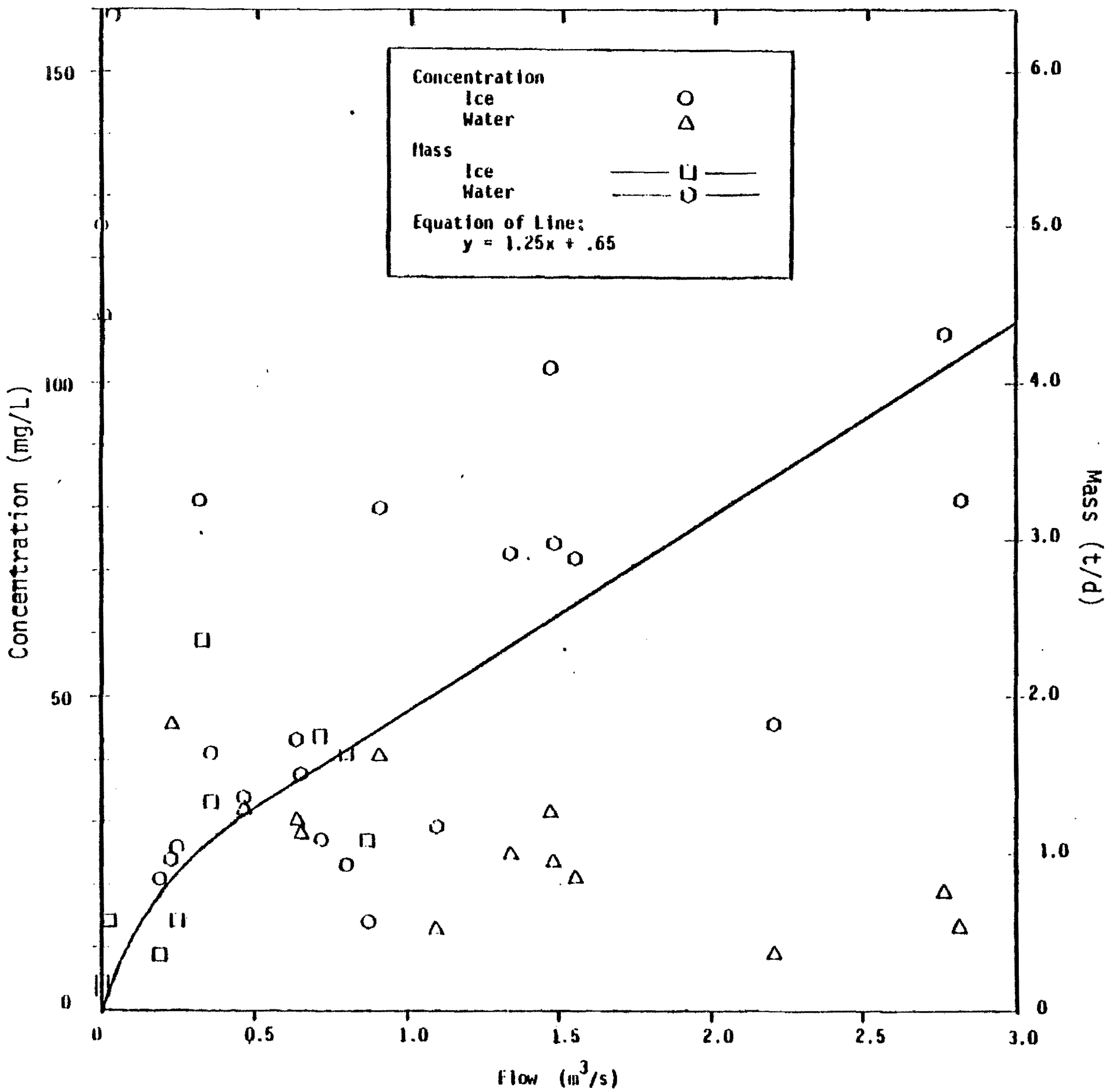


Figure 28. Dissolved chloride vs. Flow: Poplar Creek.

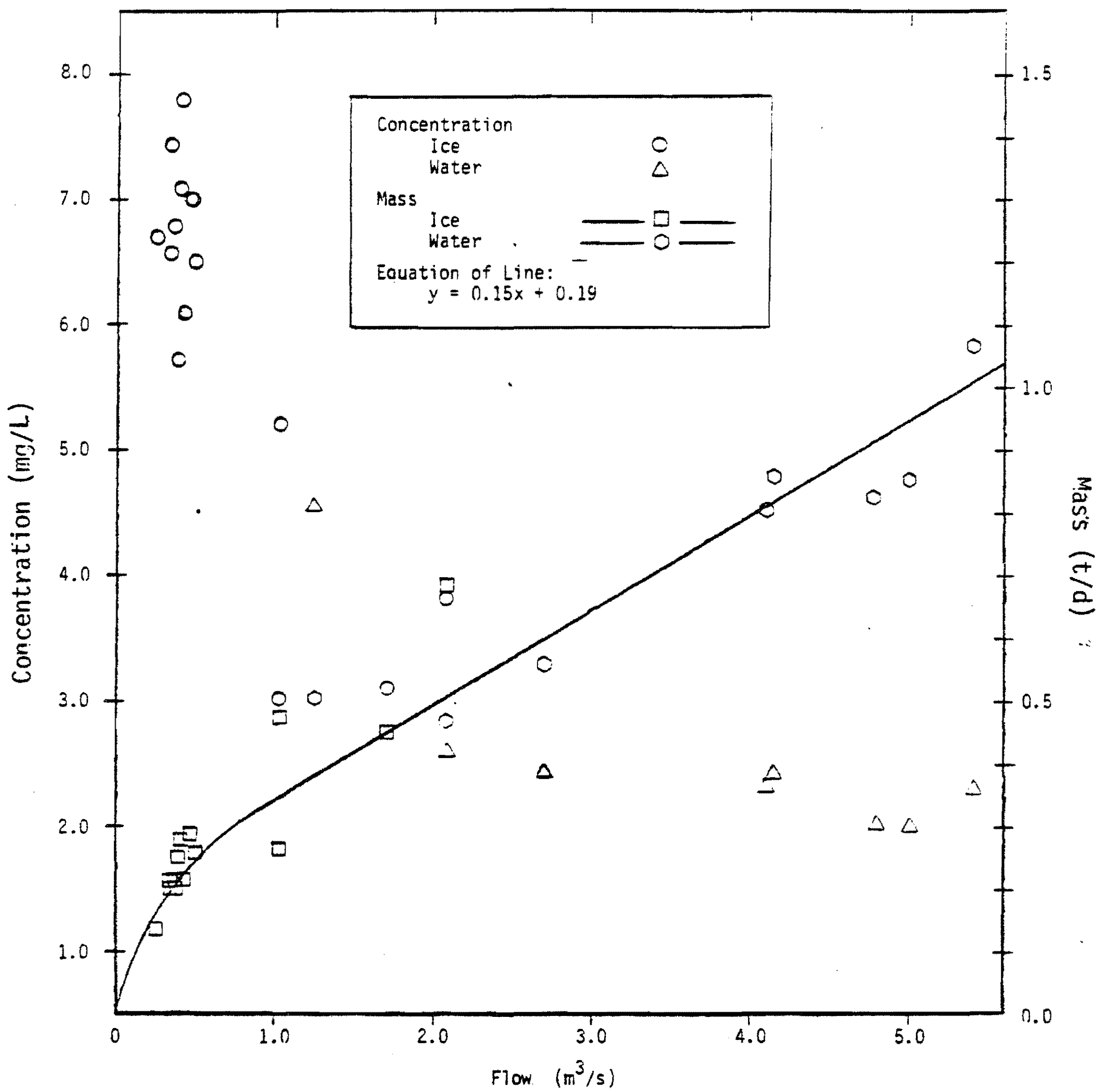


Figure 29. Dissolved chloride vs. flow: Steepbank River.

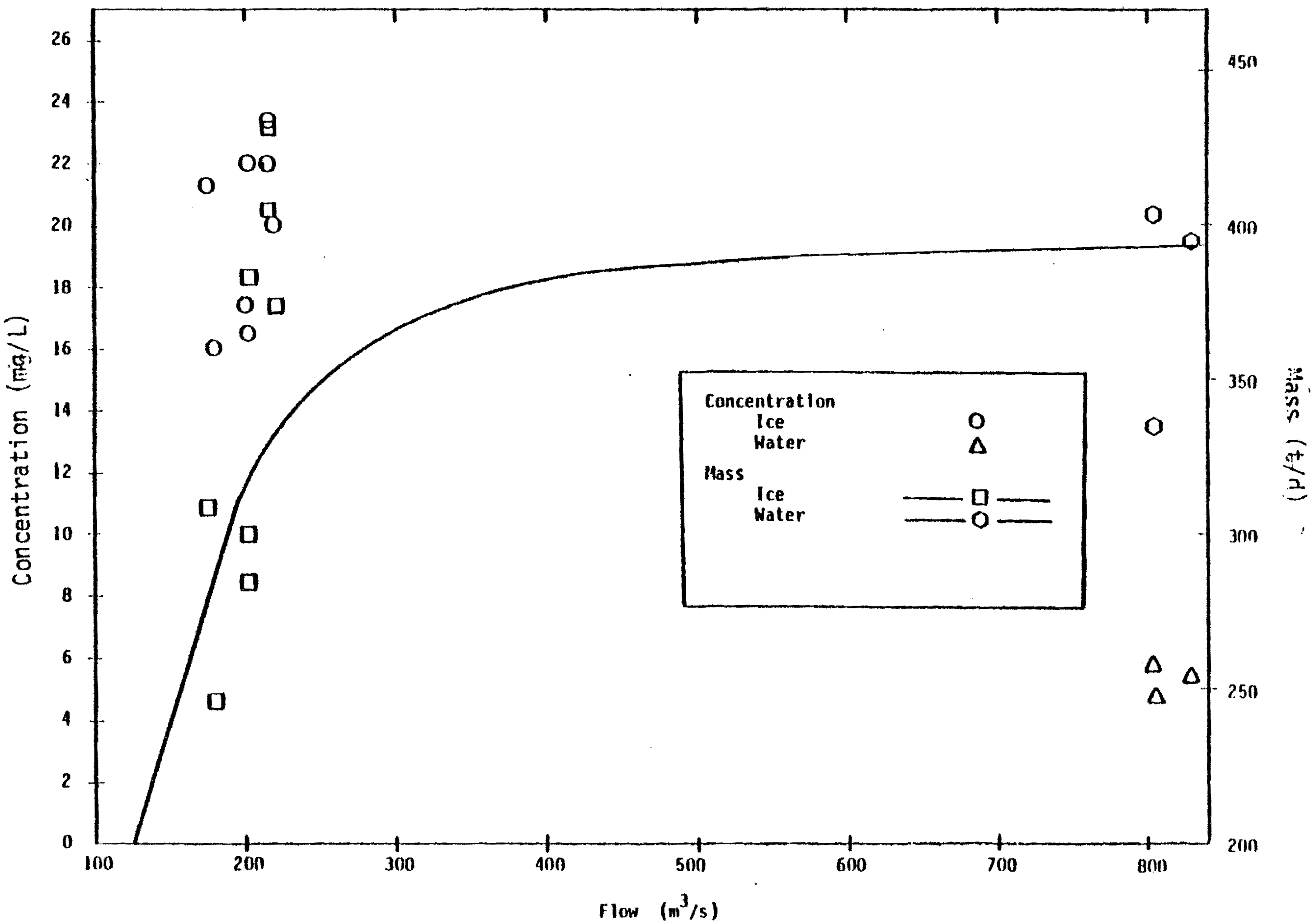


Figure 30. Dissolved chloride vs. flow: Athabasca River between the Steepbank and Muskeg Rivers.

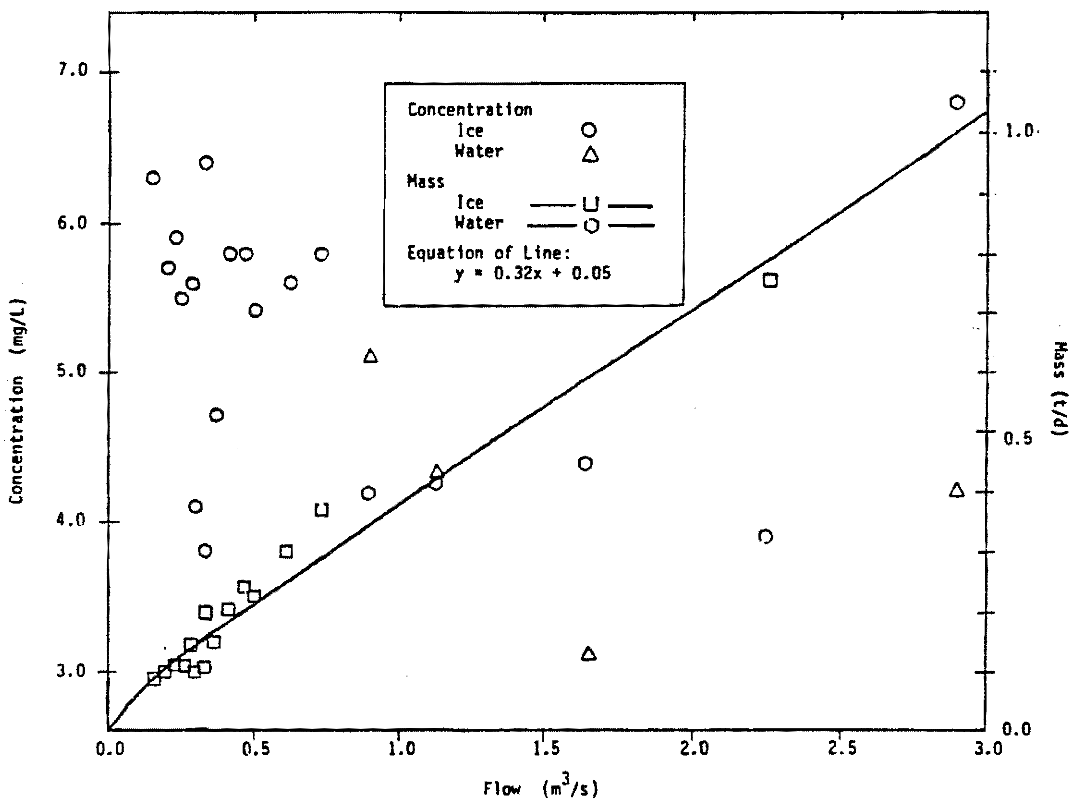


Figure 31. Dissolved chloride vs. flow: Muskeg River.

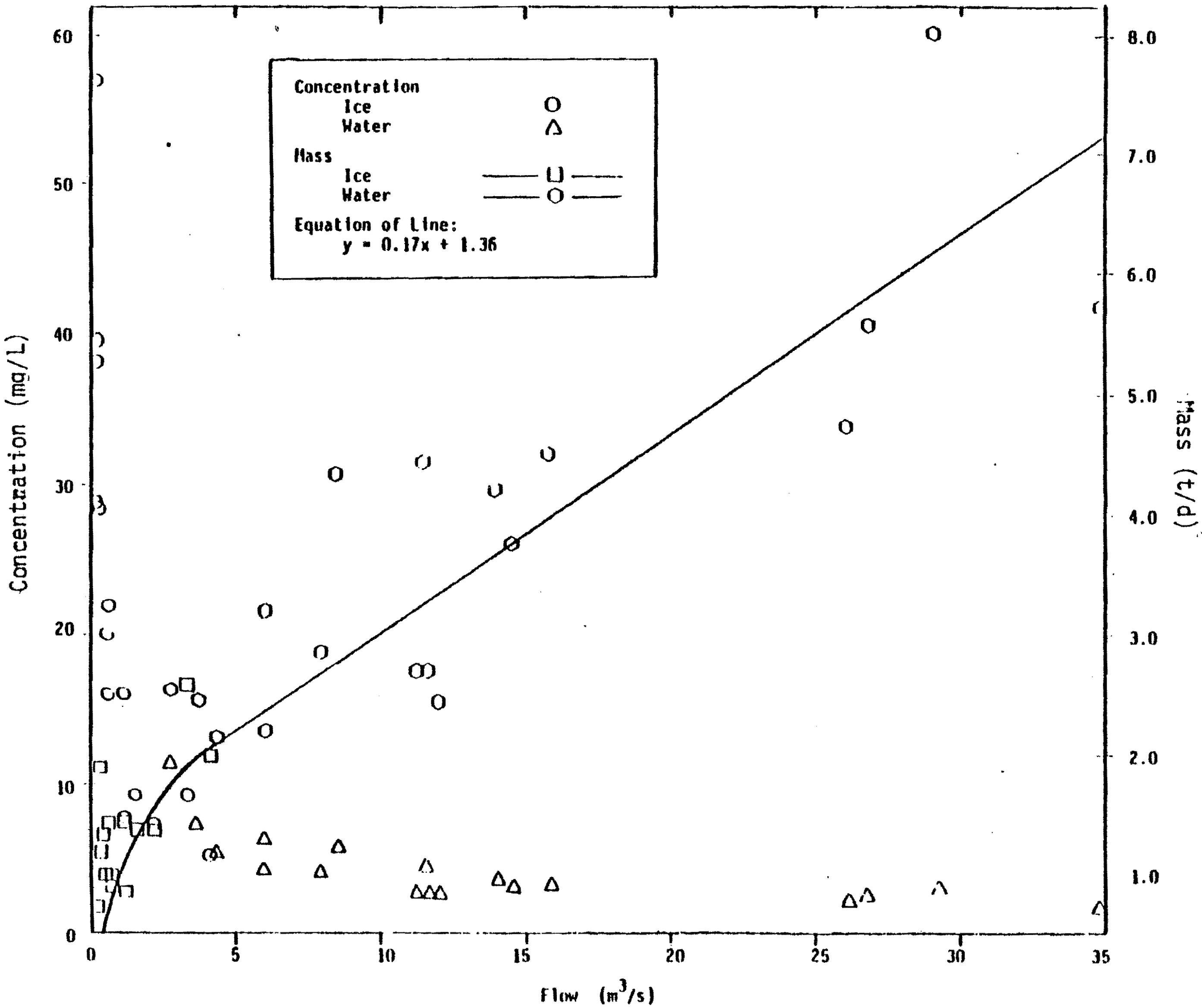


Figure 32. Dissolved chloride vs. flow: Mackay River.

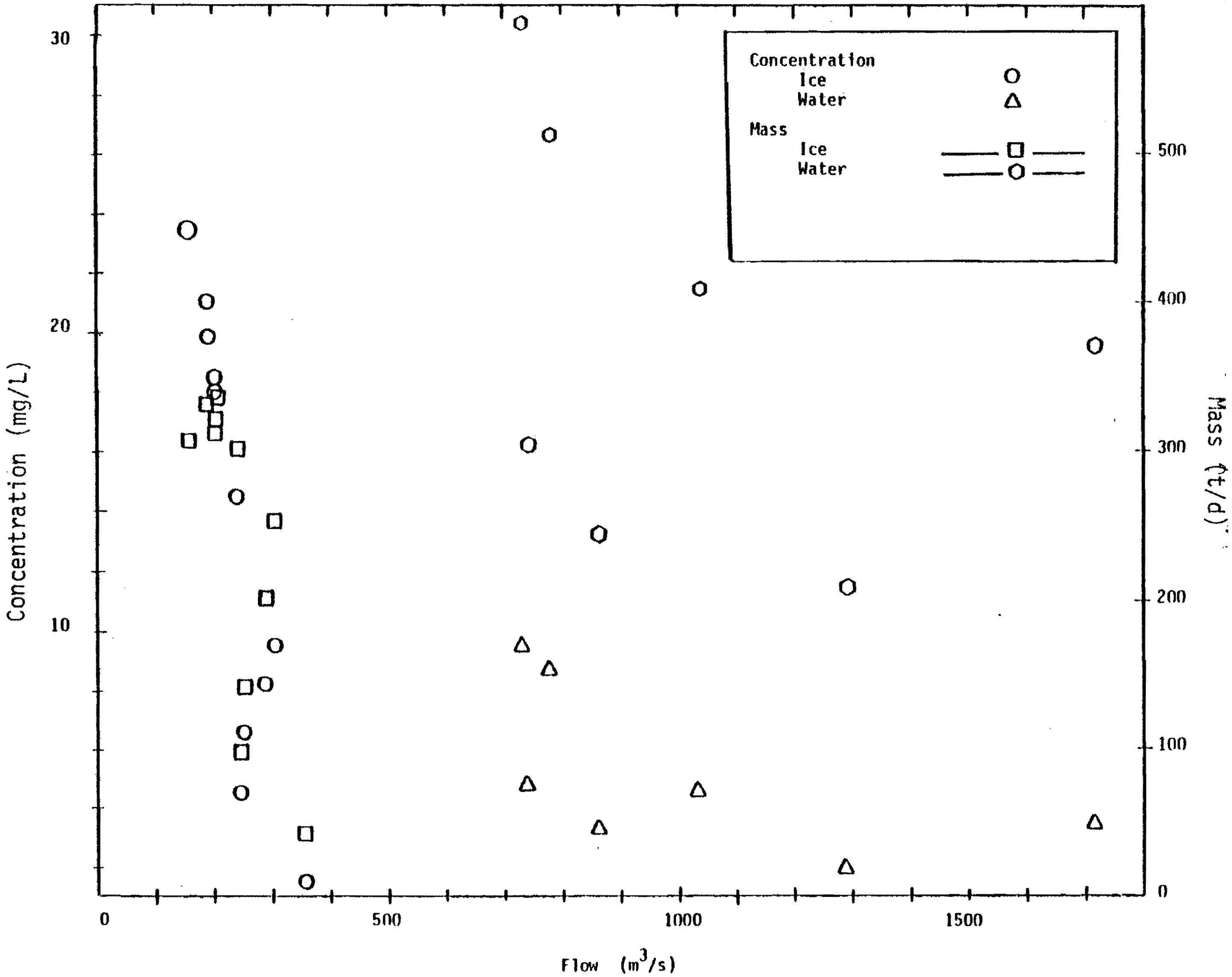


Figure 33. Dissolved chloride vs. flow: Athabasca River below Mackay River.

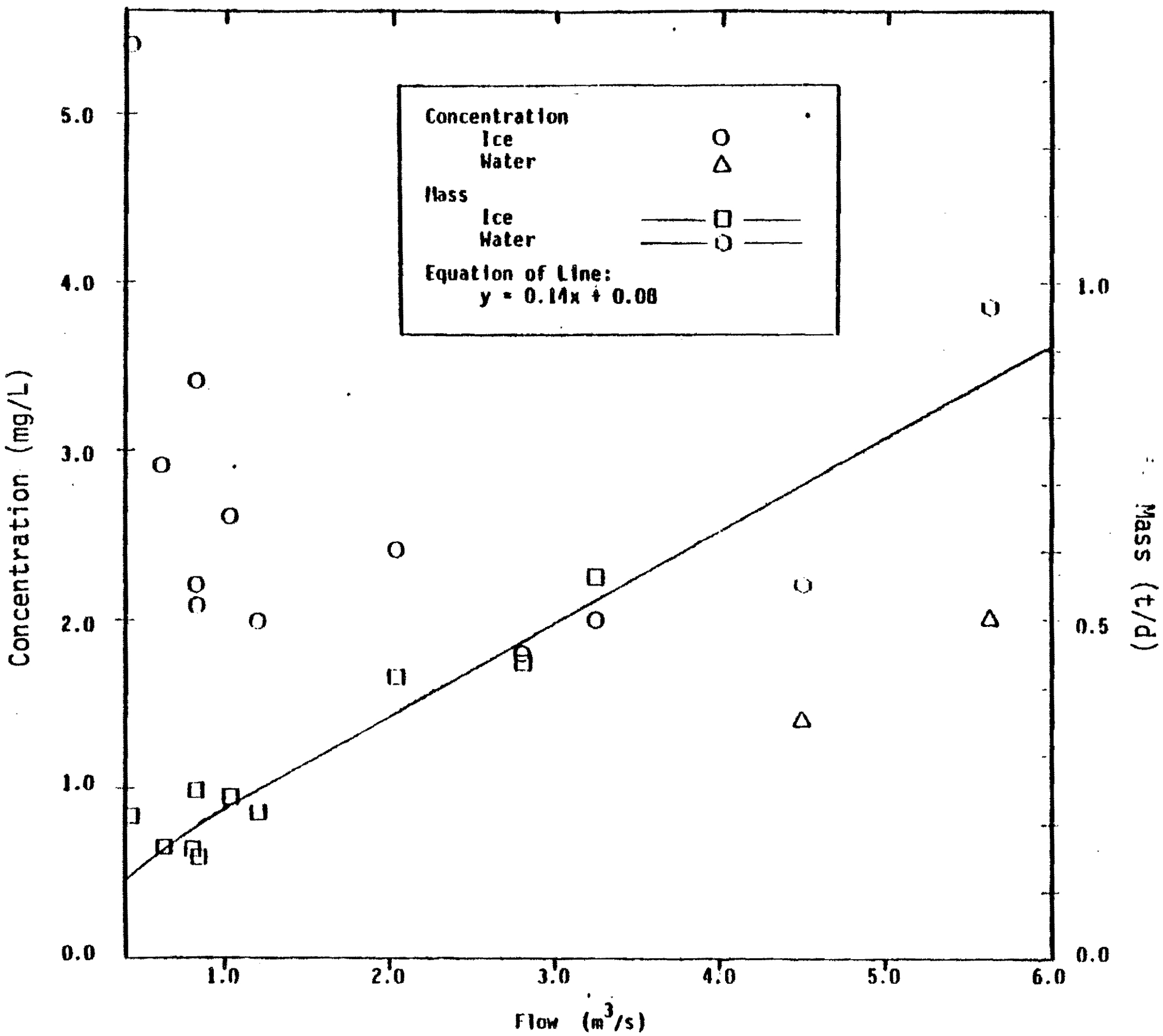


Figure 34. Dissolved chloride vs. flow: Ells River.

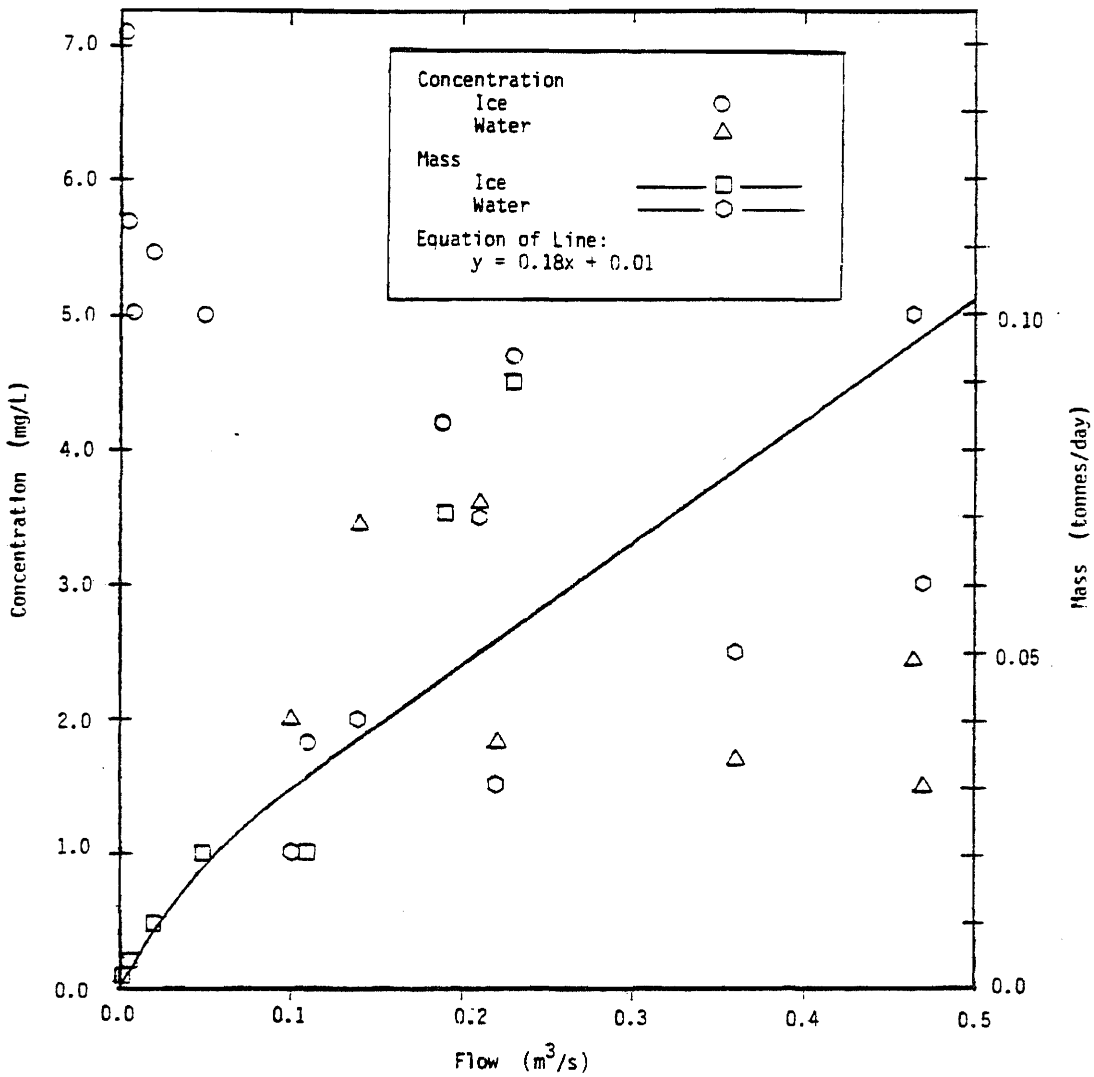


Figure 35. Dissolved chloride vs. flow: Joslyn Creek.

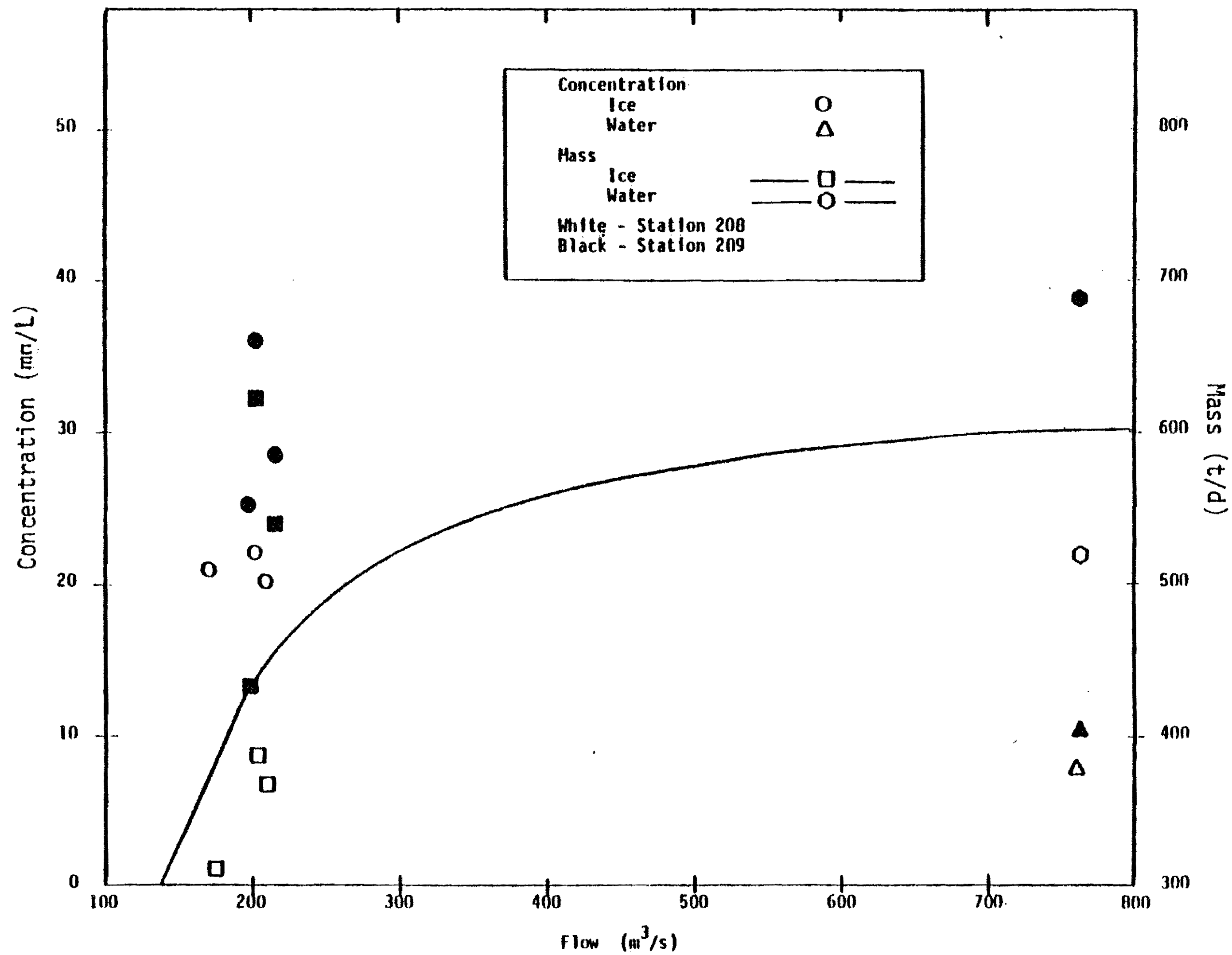


Figure 36. Dissolved chloride vs. flow: Athabasca River between Joslyn Creek and Firebag River.

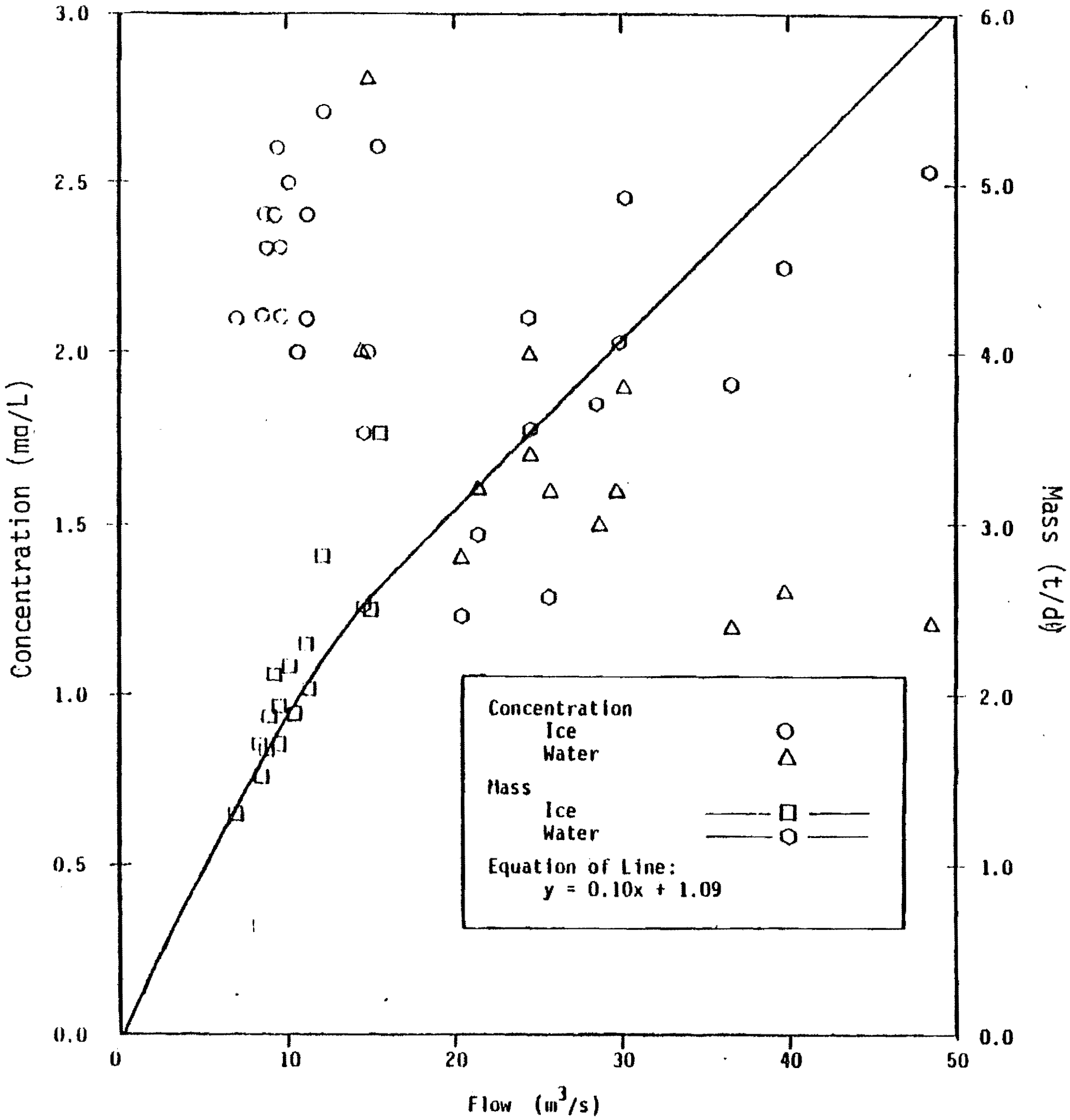


Figure 37. Dissolved chloride vs. flow: Firebag River.

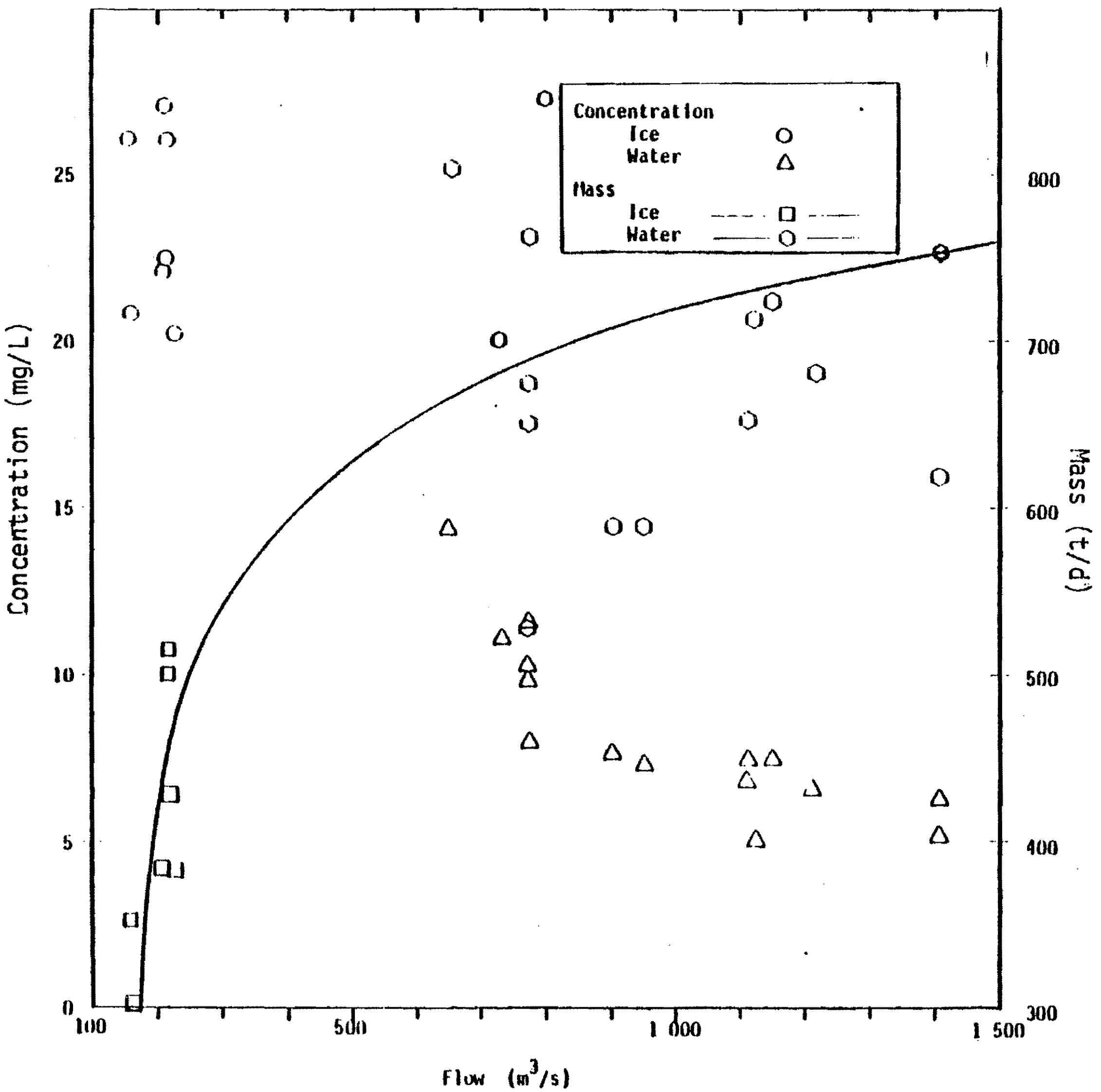


Figure 38. Dissolved chloride vs. flow: Athabasca River at Embarras.

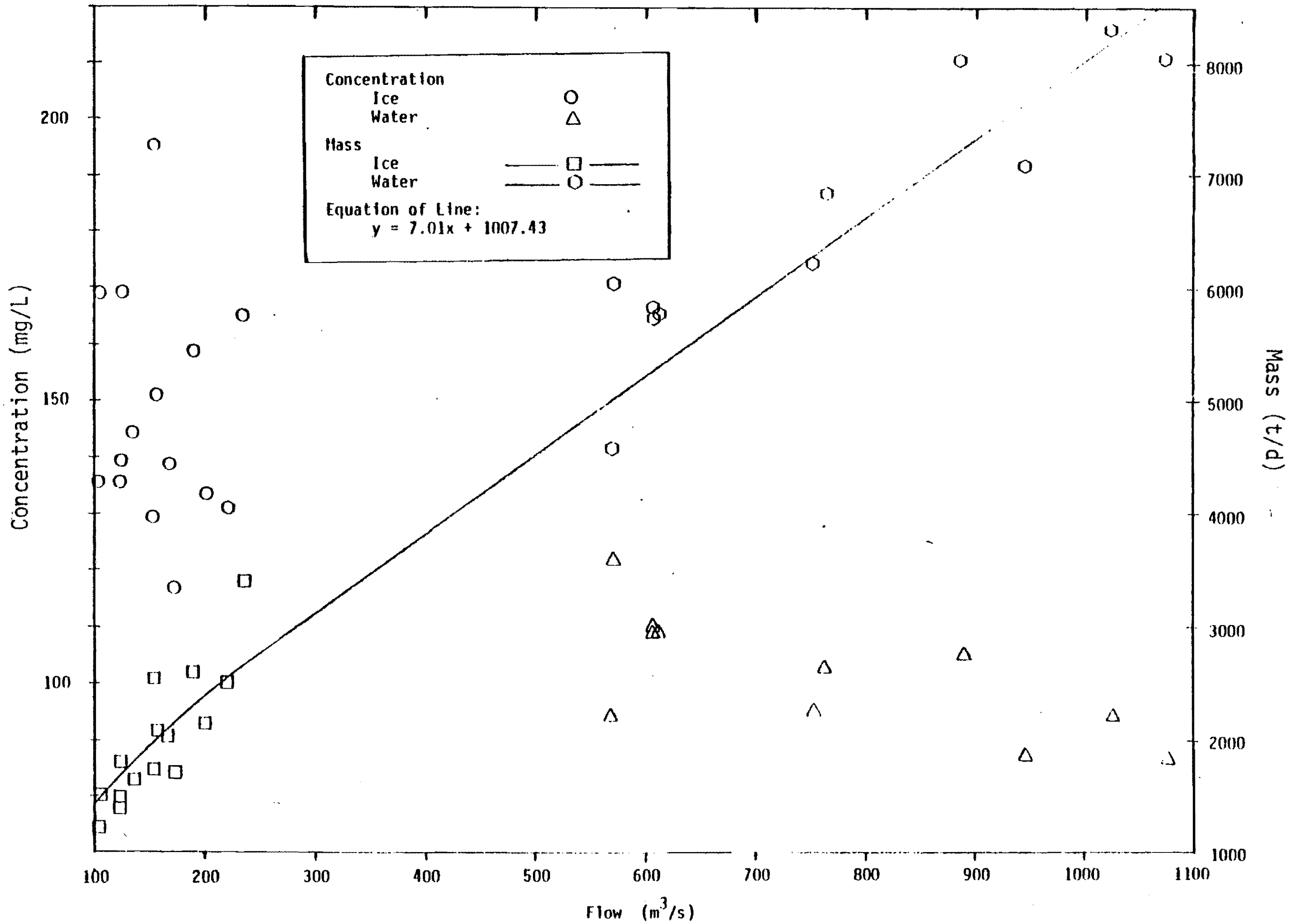


Figure 39. Total alkanity vs. flow: Athabasca River above Horse River.

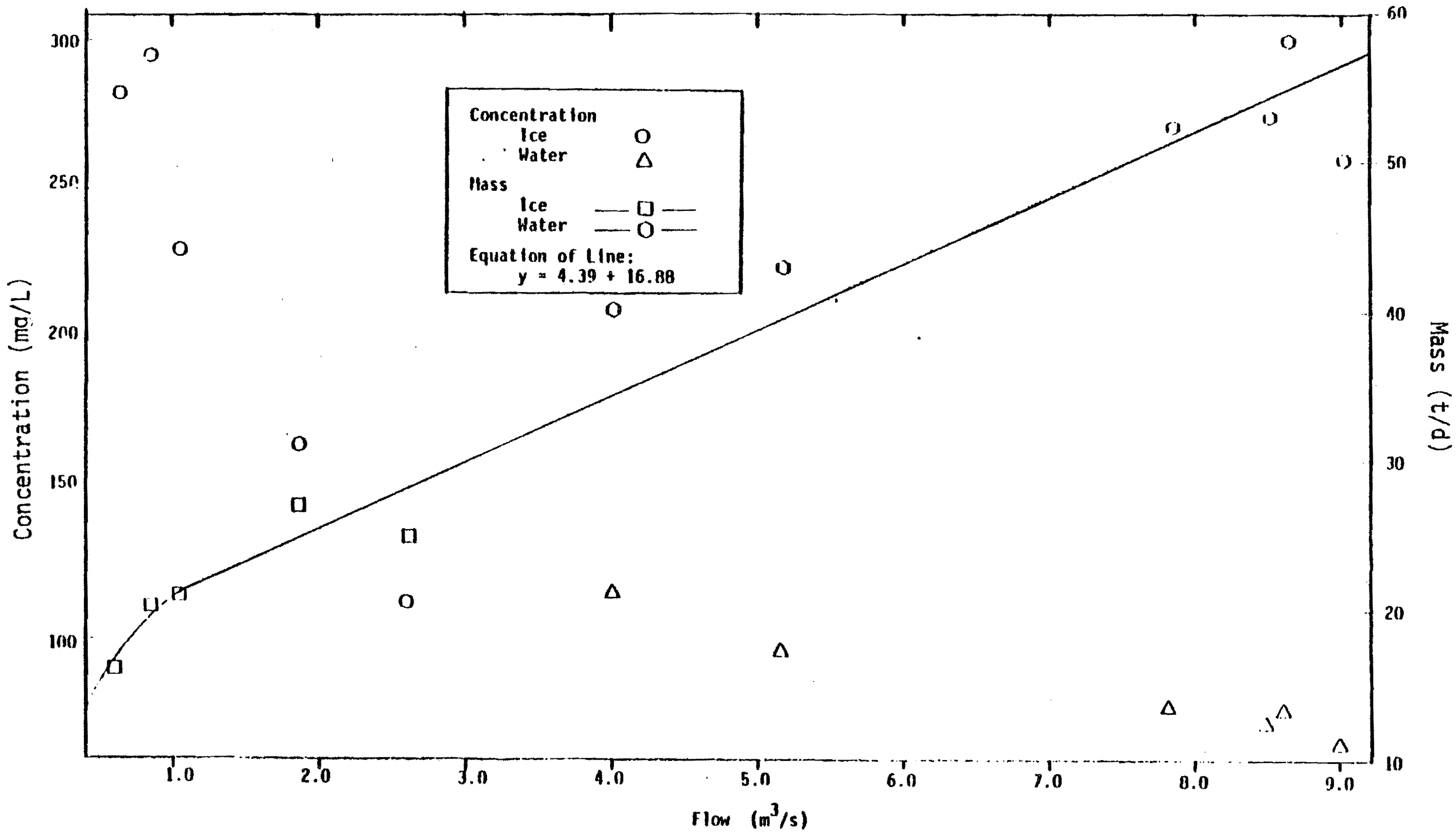


Figure 40: Total alkanity vs. flow: Horse River.

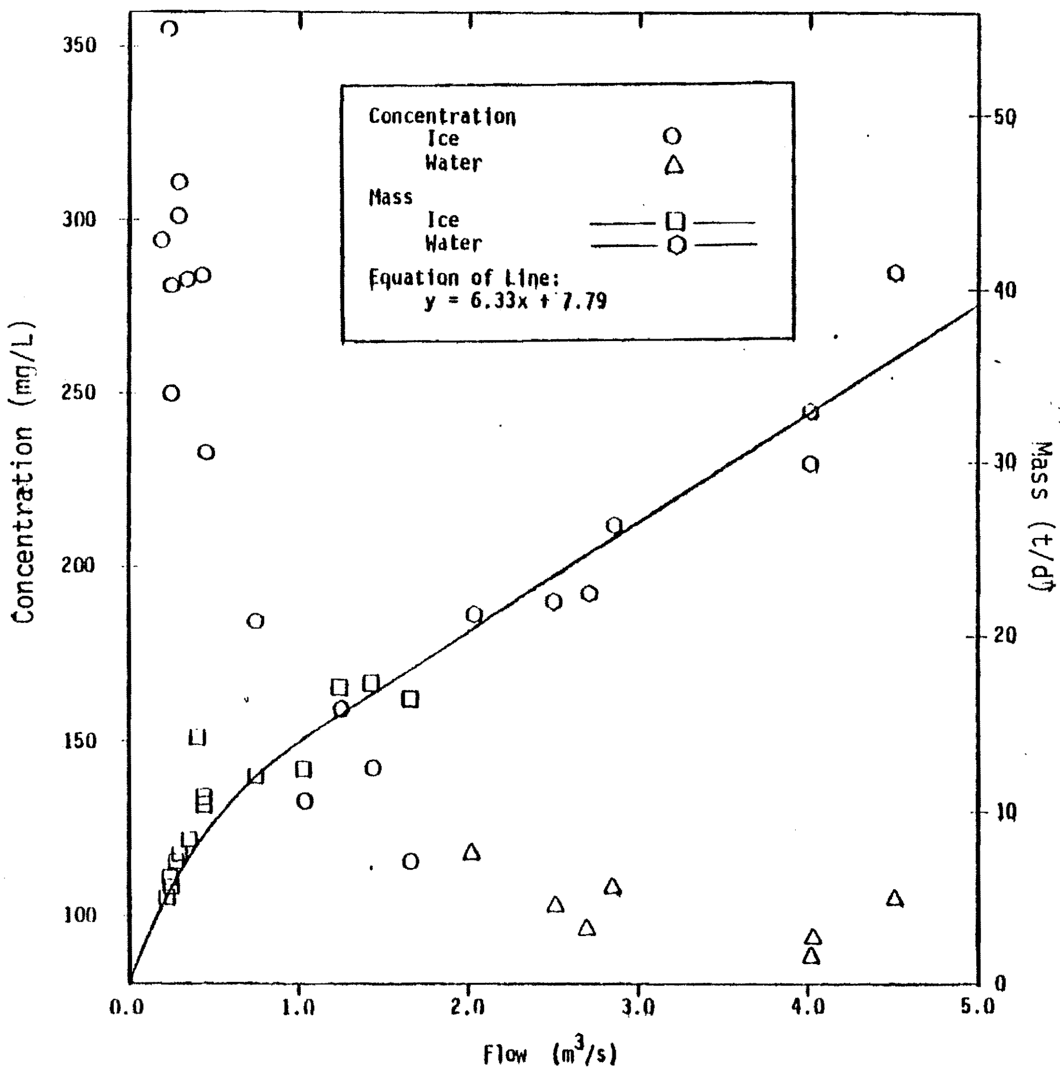


Figure 41. Total alkanity vs. flow: Hangingstone River.

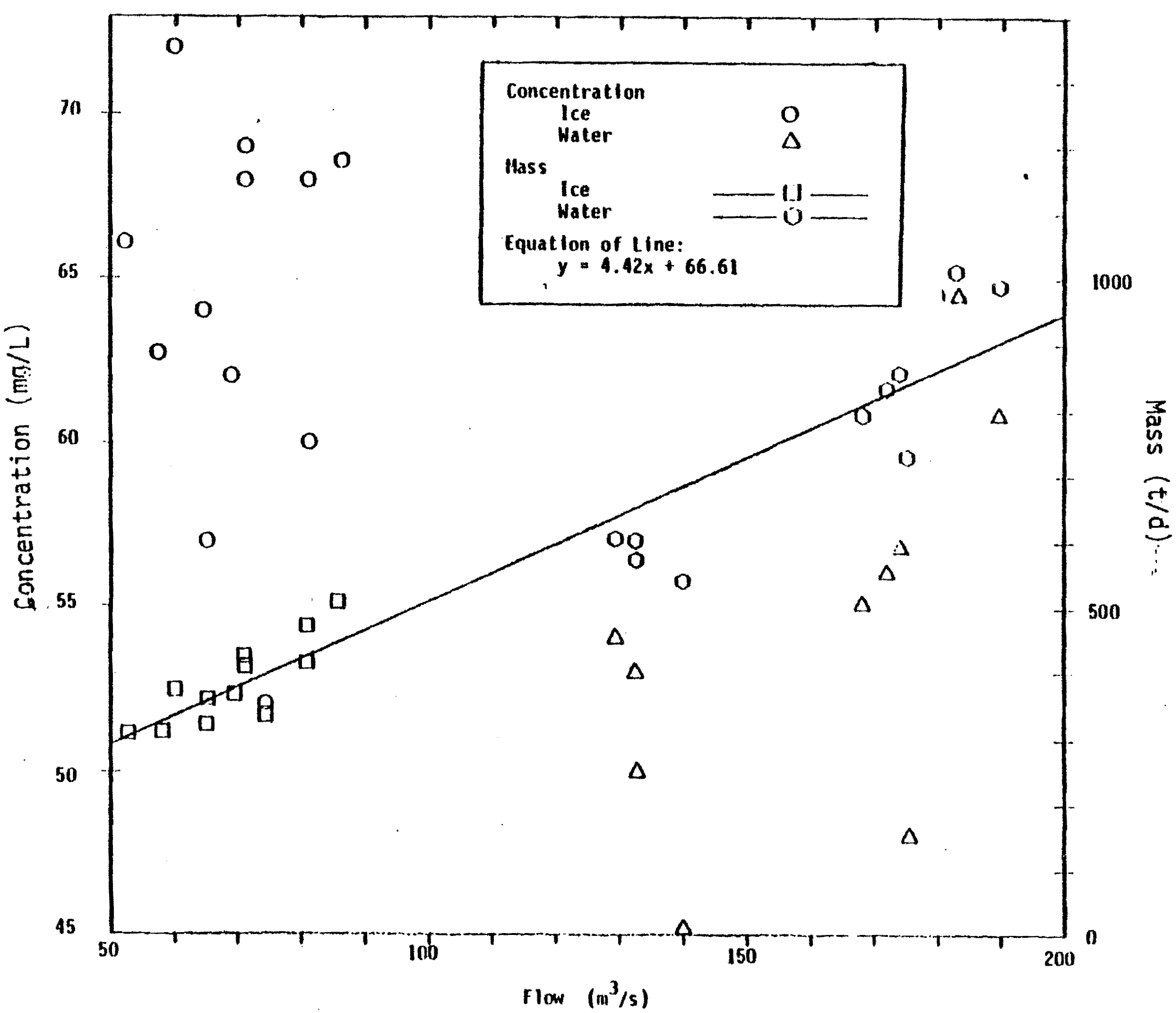
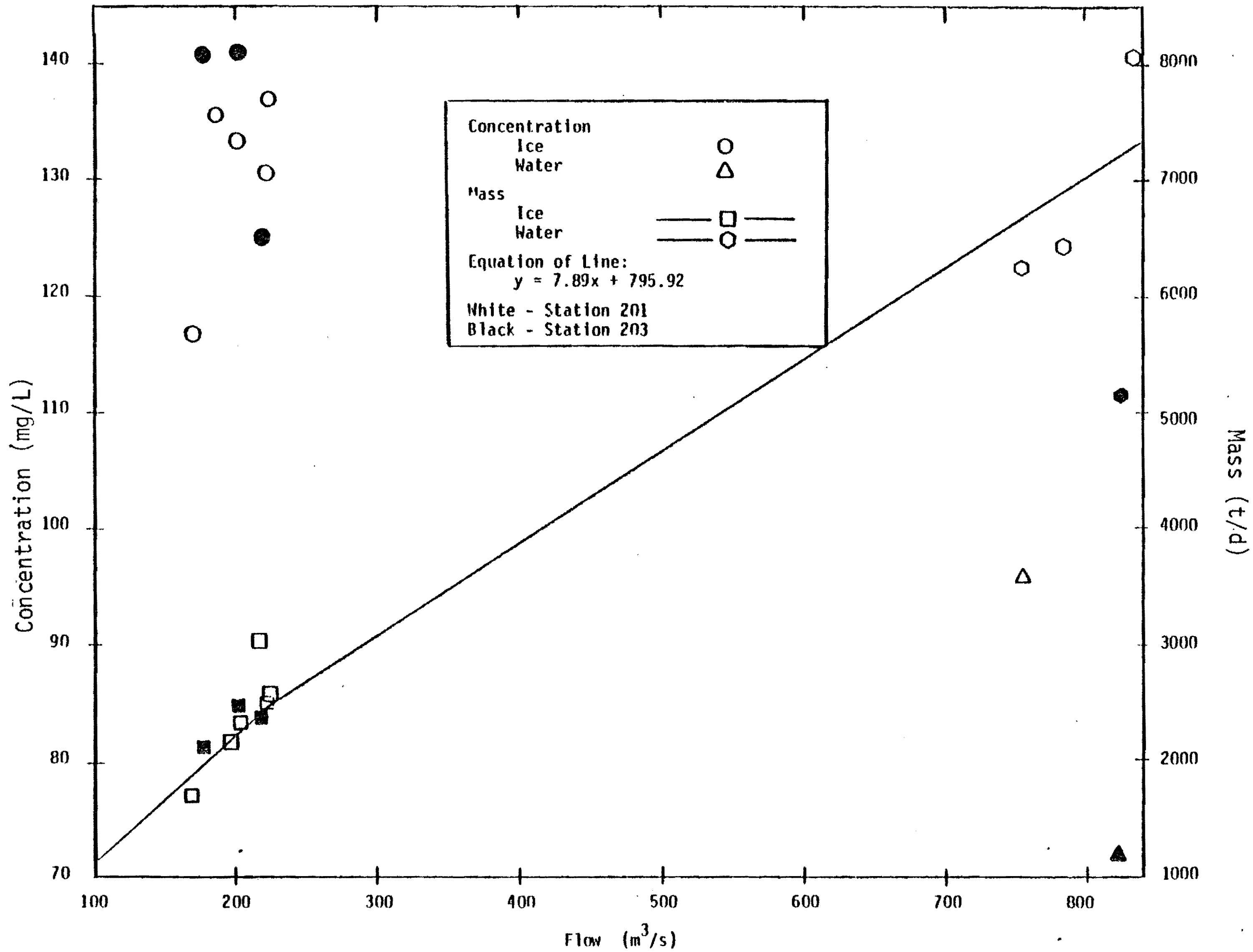


Figure 42. Total alkanity vs. flow: Clearwater River.



Fogire 43. Total alkanitv vs. flow: Athabasca River between Clearwater River and Poplar Creek.

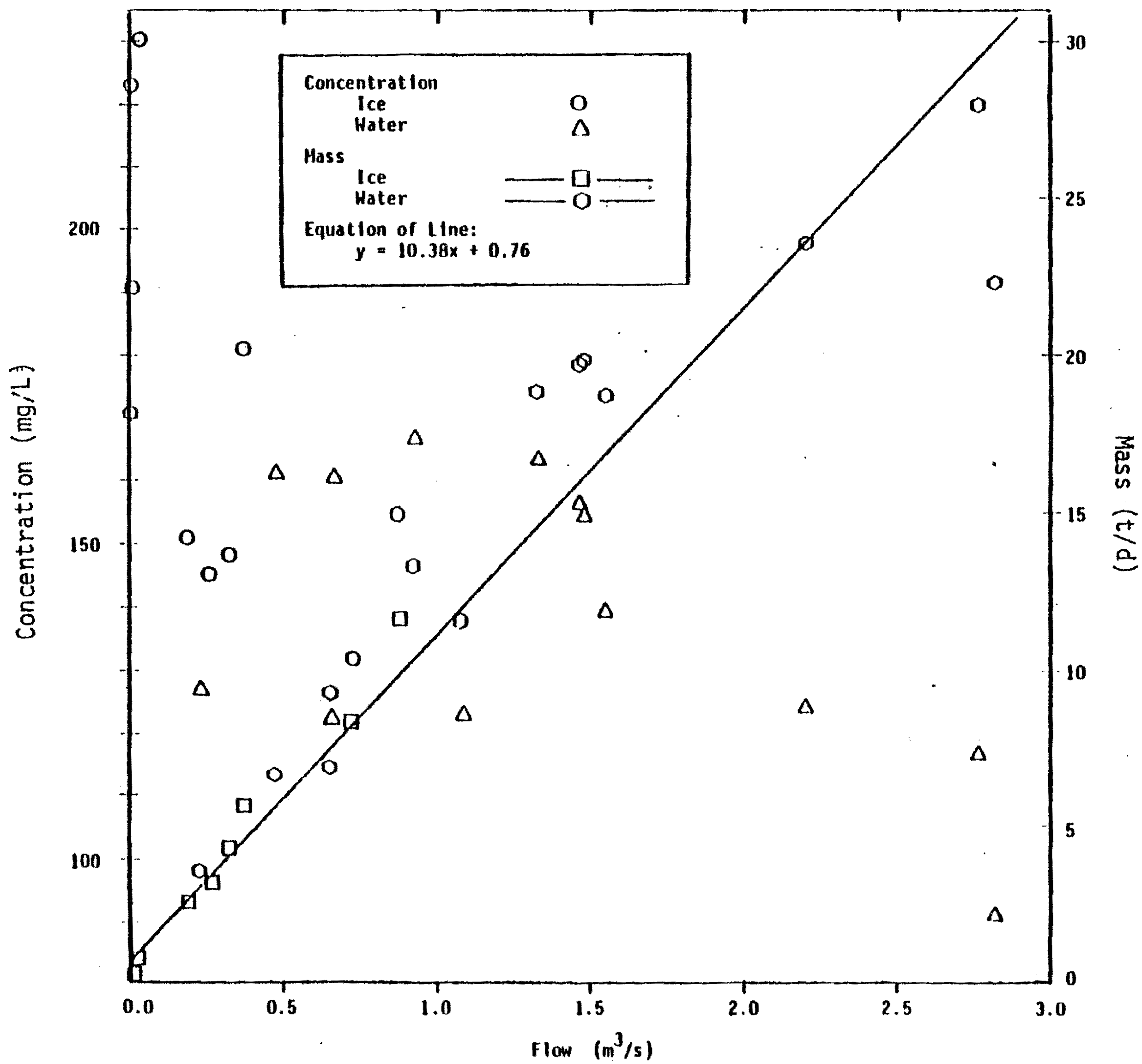


Figure 44. Total alkanity vs. flow: Poplar Creek.

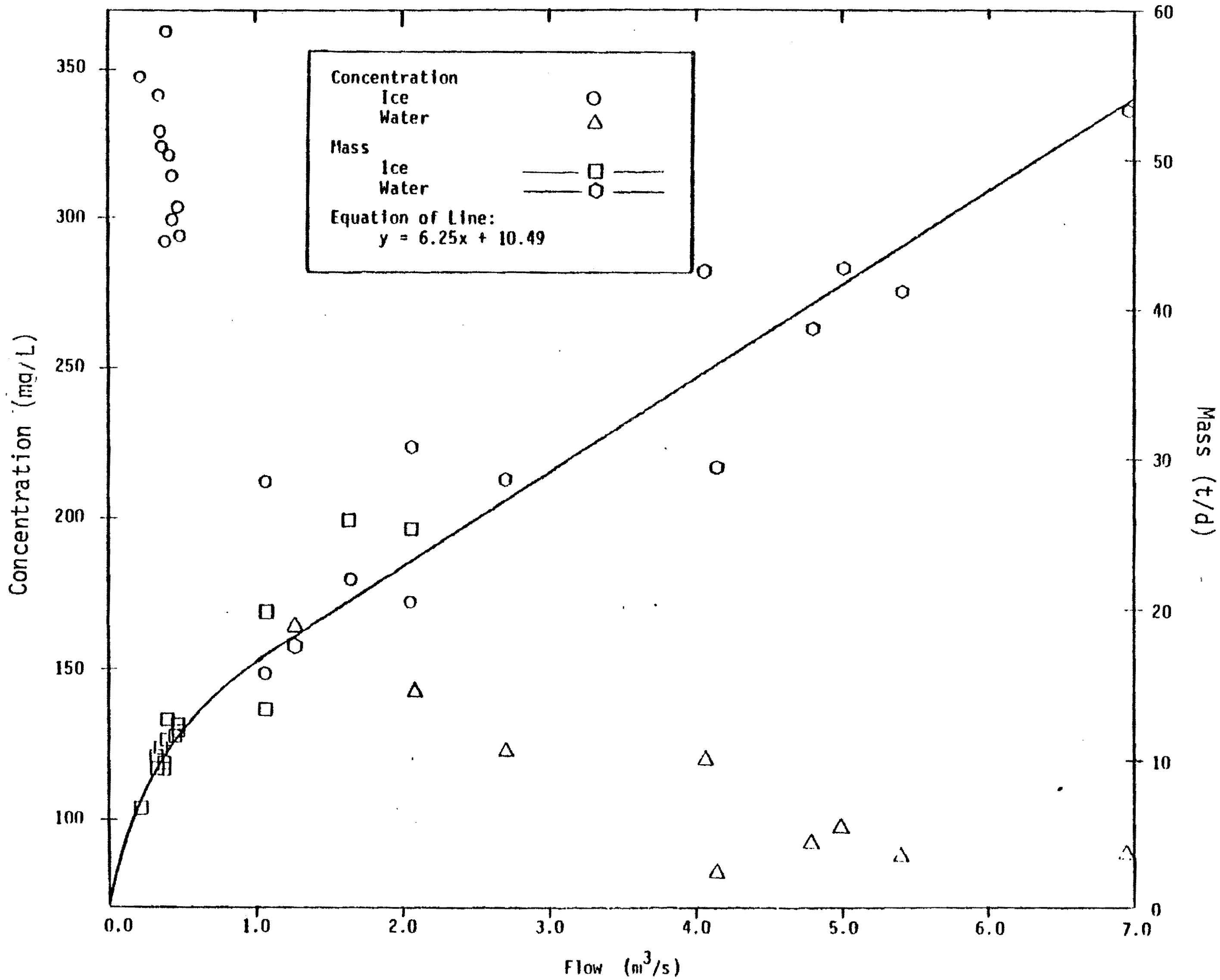


Figure 45. Total alkanity vs. flow: Steenbank River.

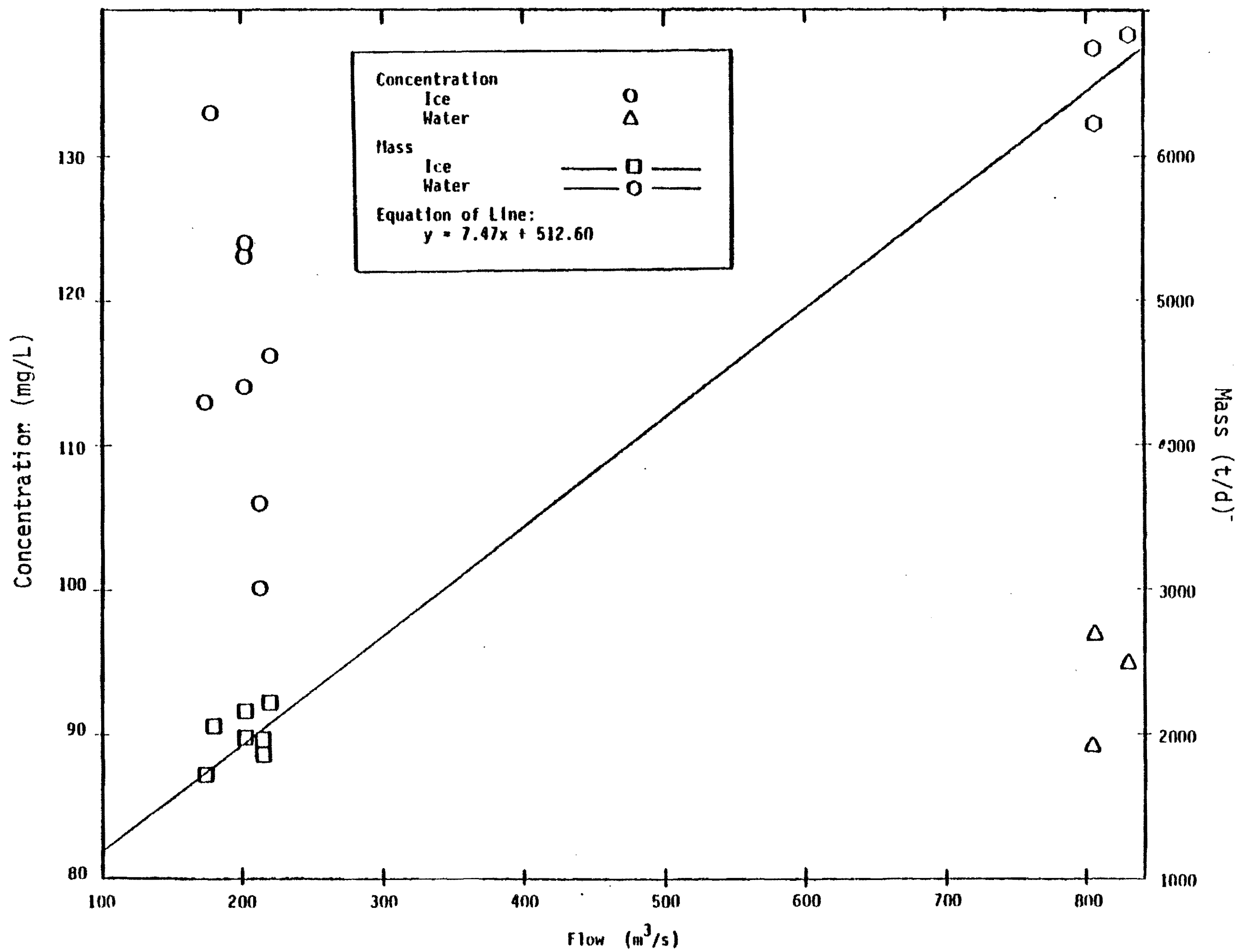


Figure 46. Total alkanity vs. flow: Athabasca River between the Steepbank and Muskeg Rivers.

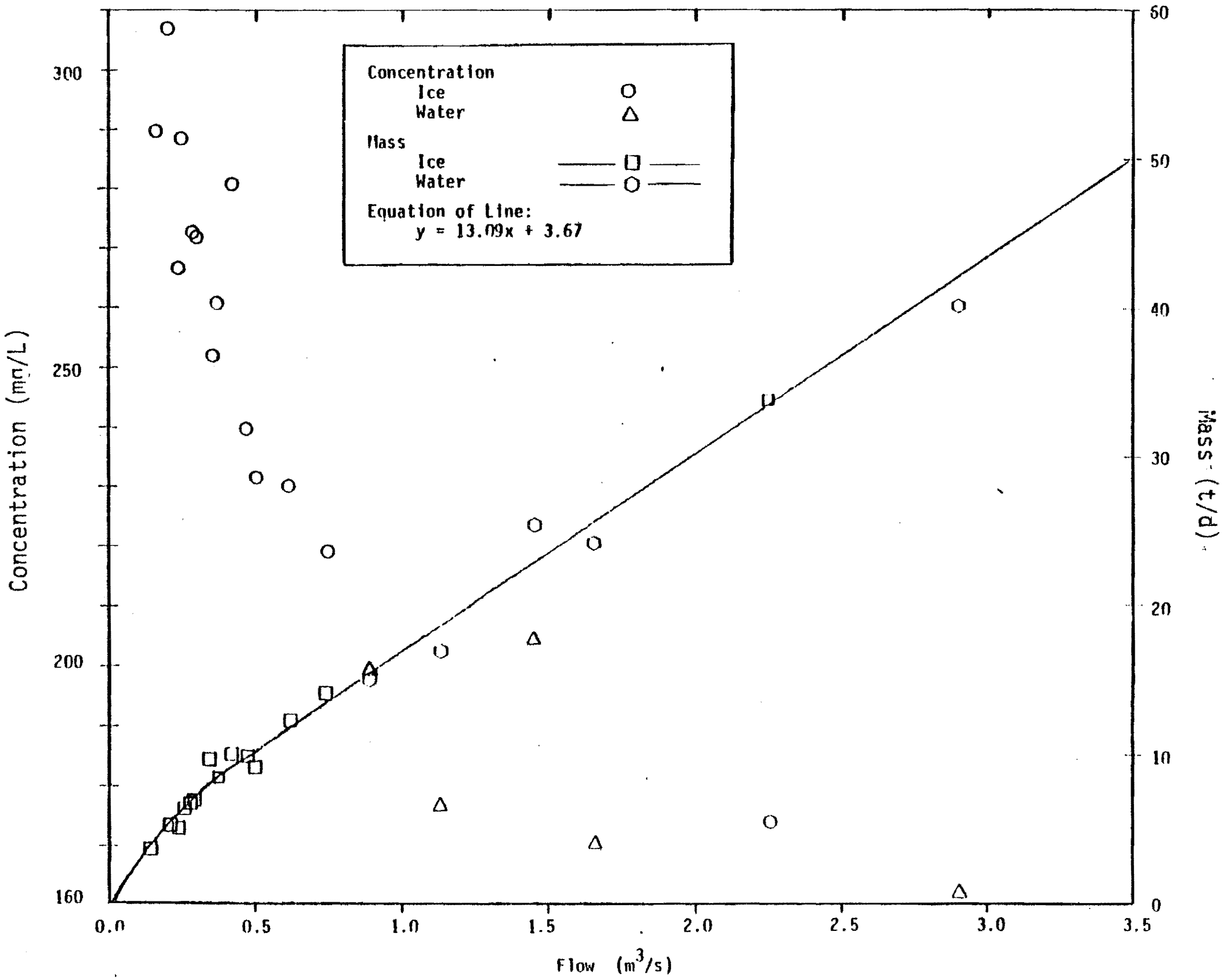


Figure 47. Total alkanity vs. flow: Muskeg River.

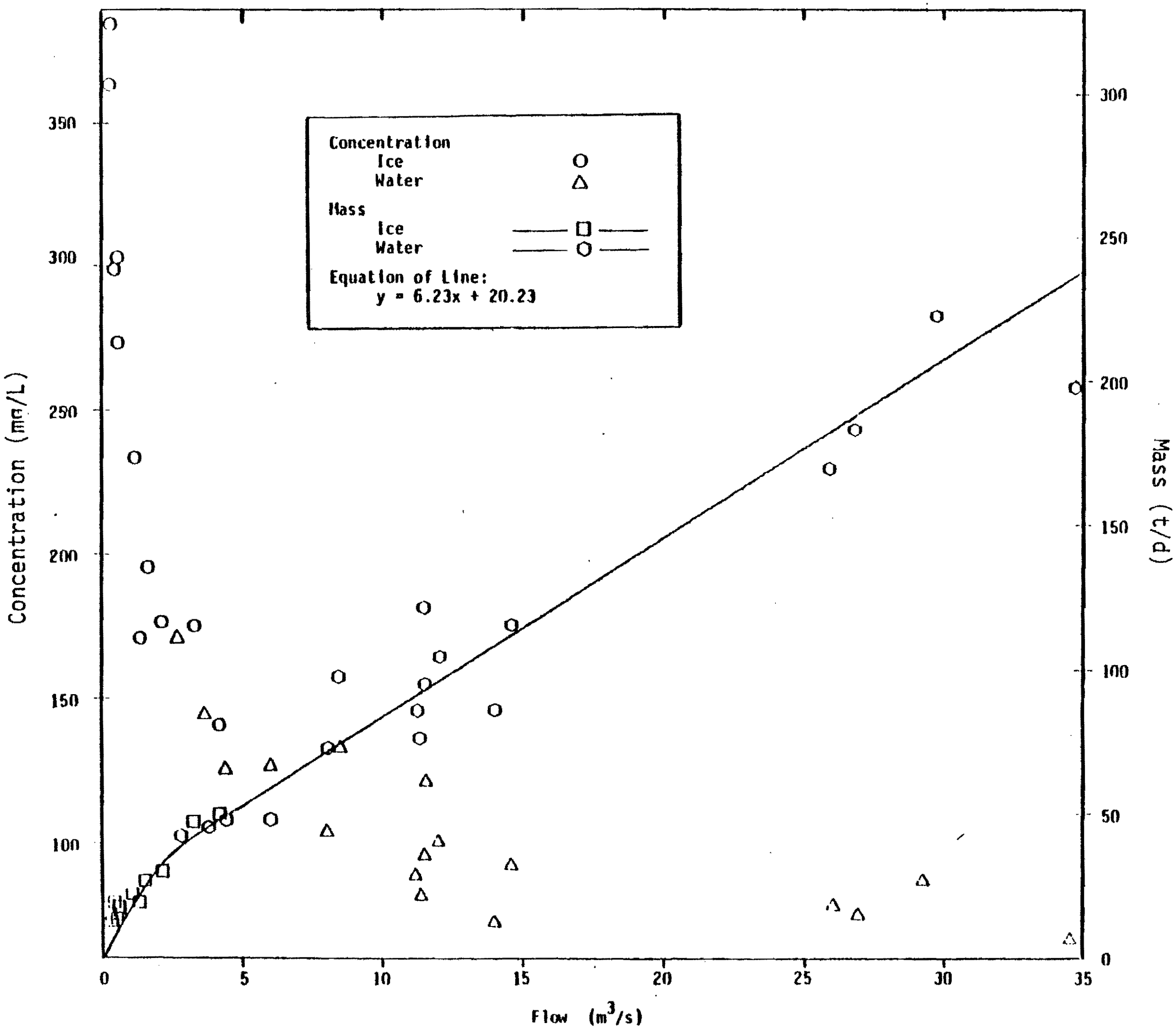


Figure 48. Dissolved alkalinity vs. flow: Mackay River.

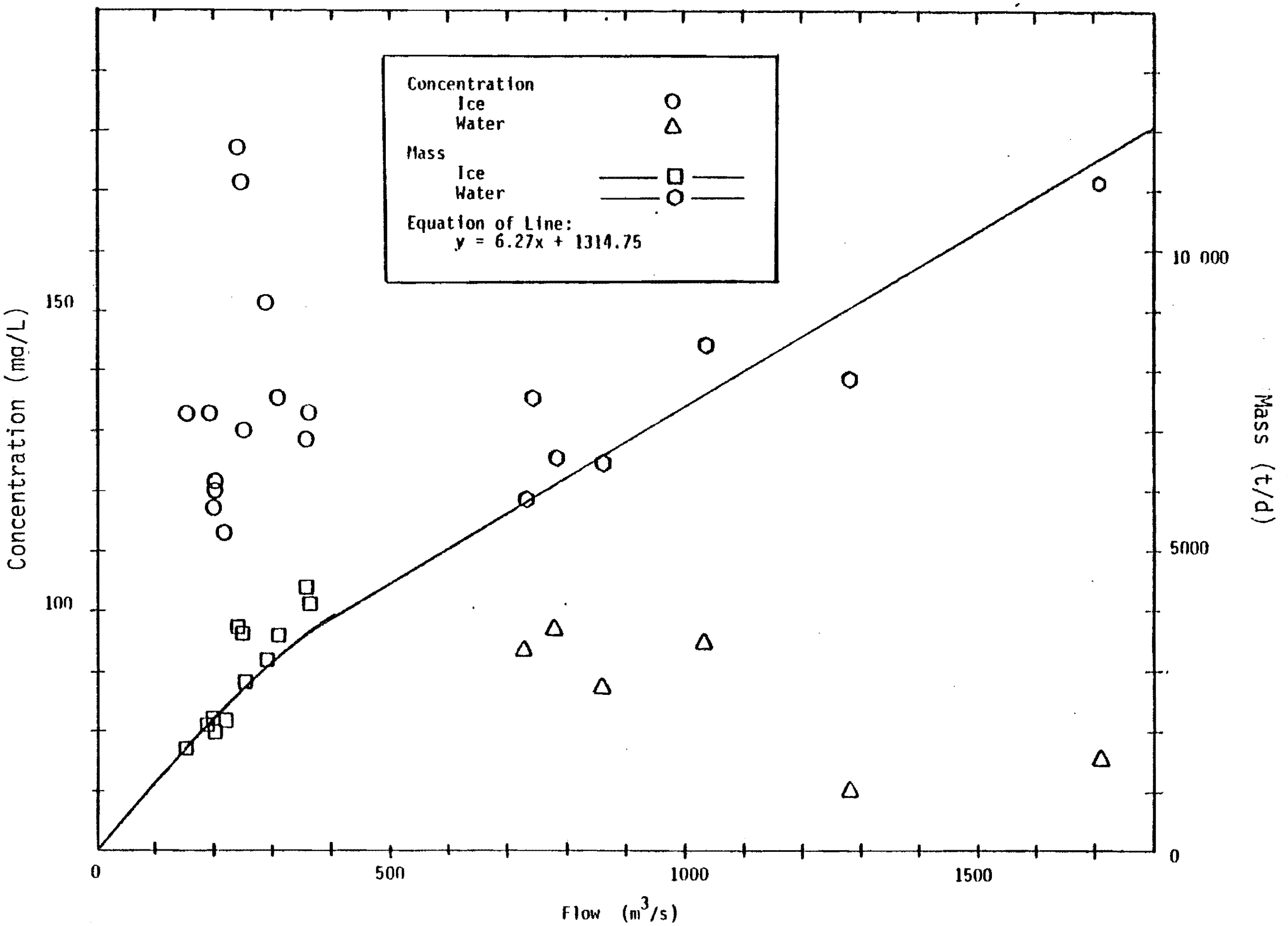


Figure 49. Dissolved alkanity vs. flow: Athabasca River below Mackay River.

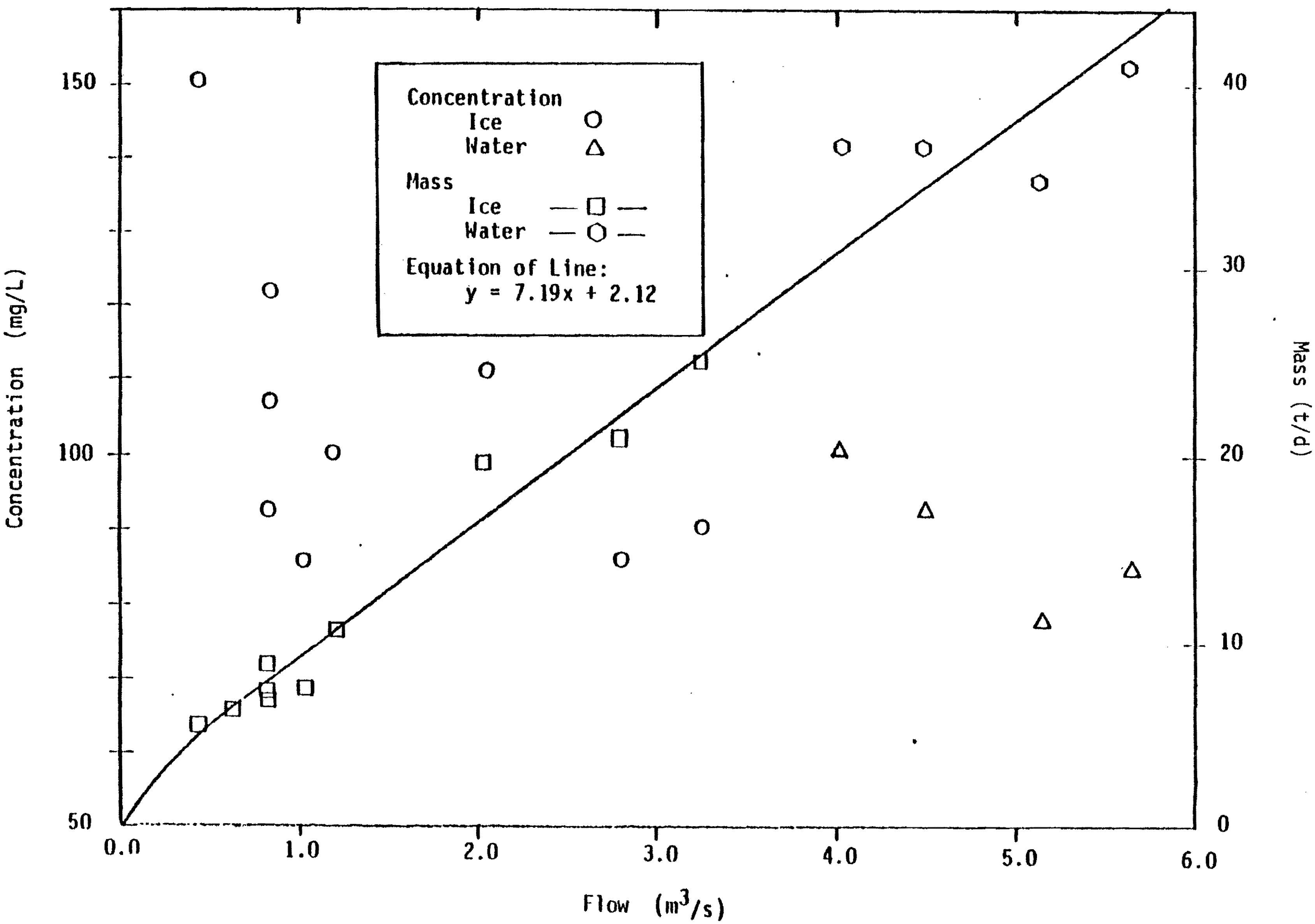


Figure 50. Dissolved alkanity vs. flow: Ells River.

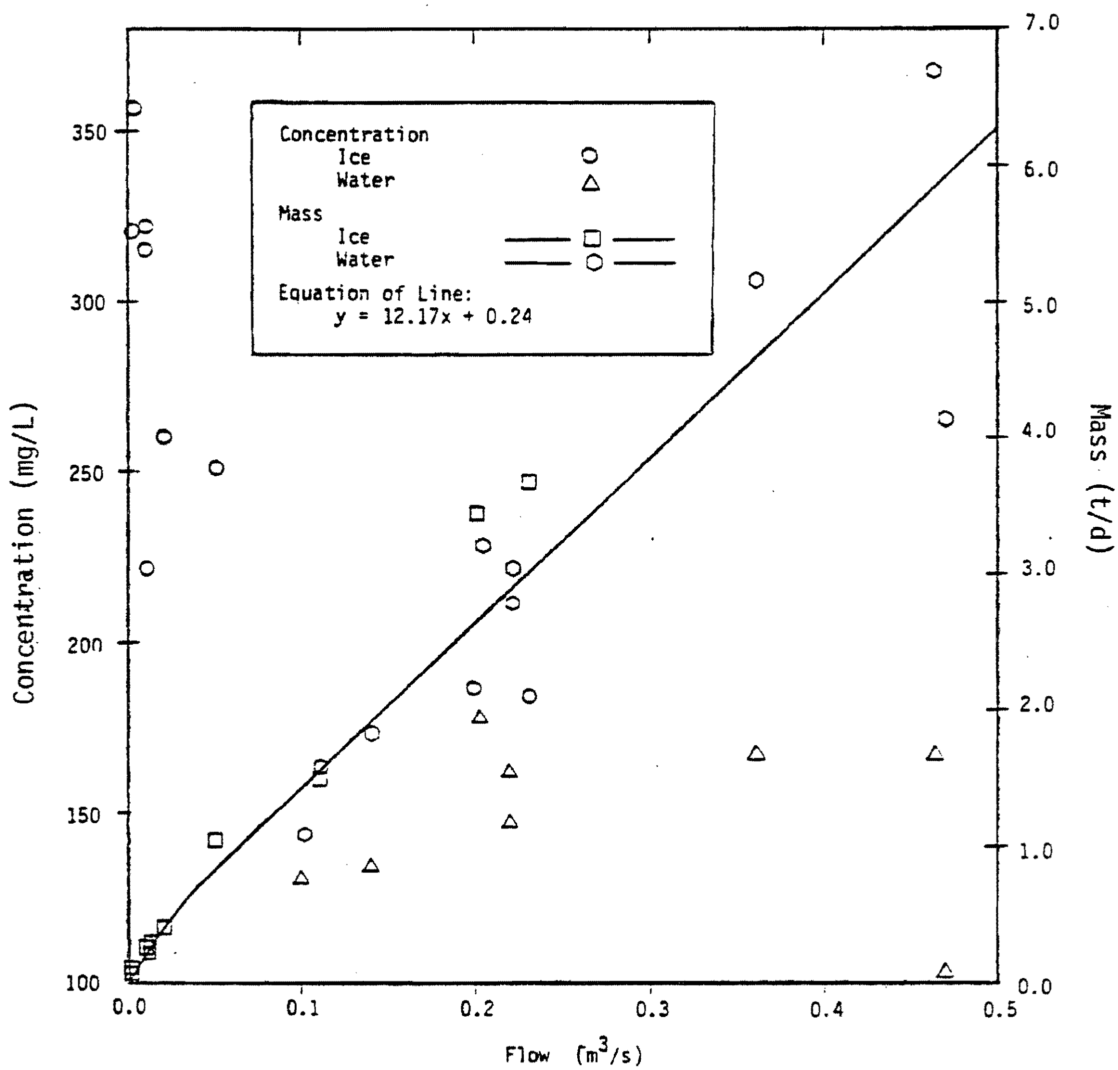


Figure 51. Dissolved alkanity vs. flow: Joslyn Creek.

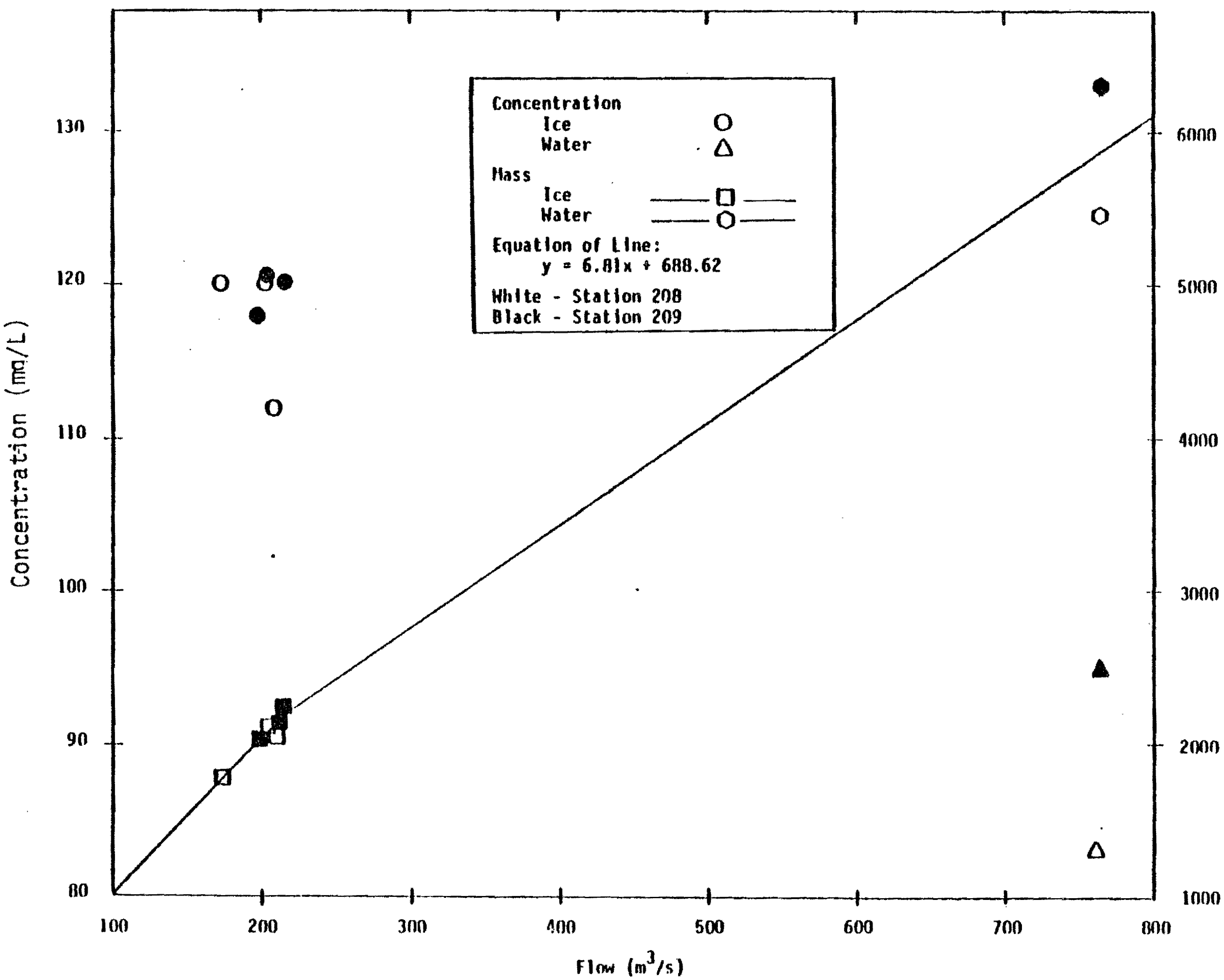


Figure 52. Dissolved alkanity vs. flow: Athabasca River between Joslyn Creek and Firebag River.

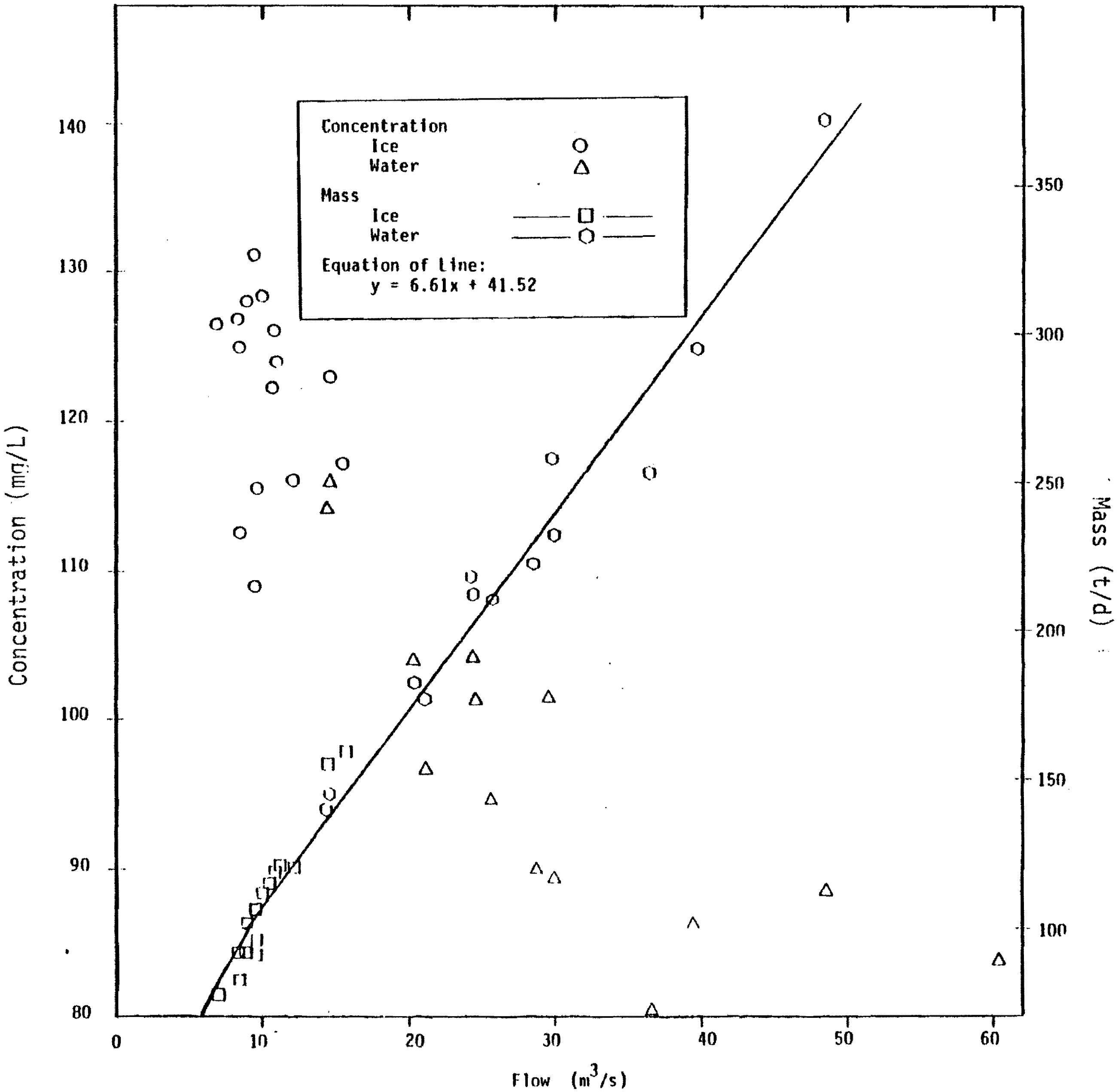


Figure 53. Dissolved alkanity vs. flow: Firebag River.

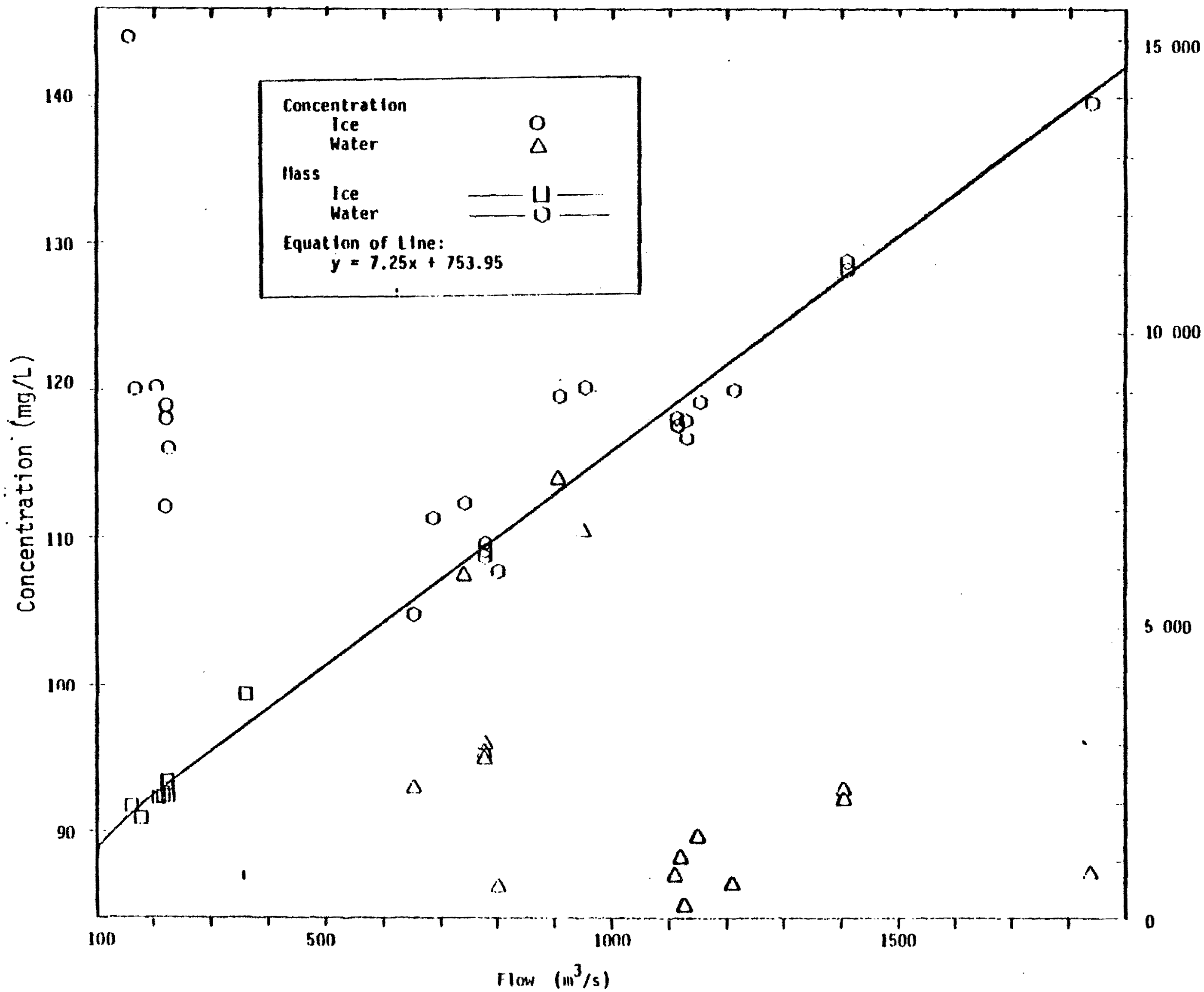


Figure 54. Dissolved alkanity vs. flow: Athabasca River at Embarras.

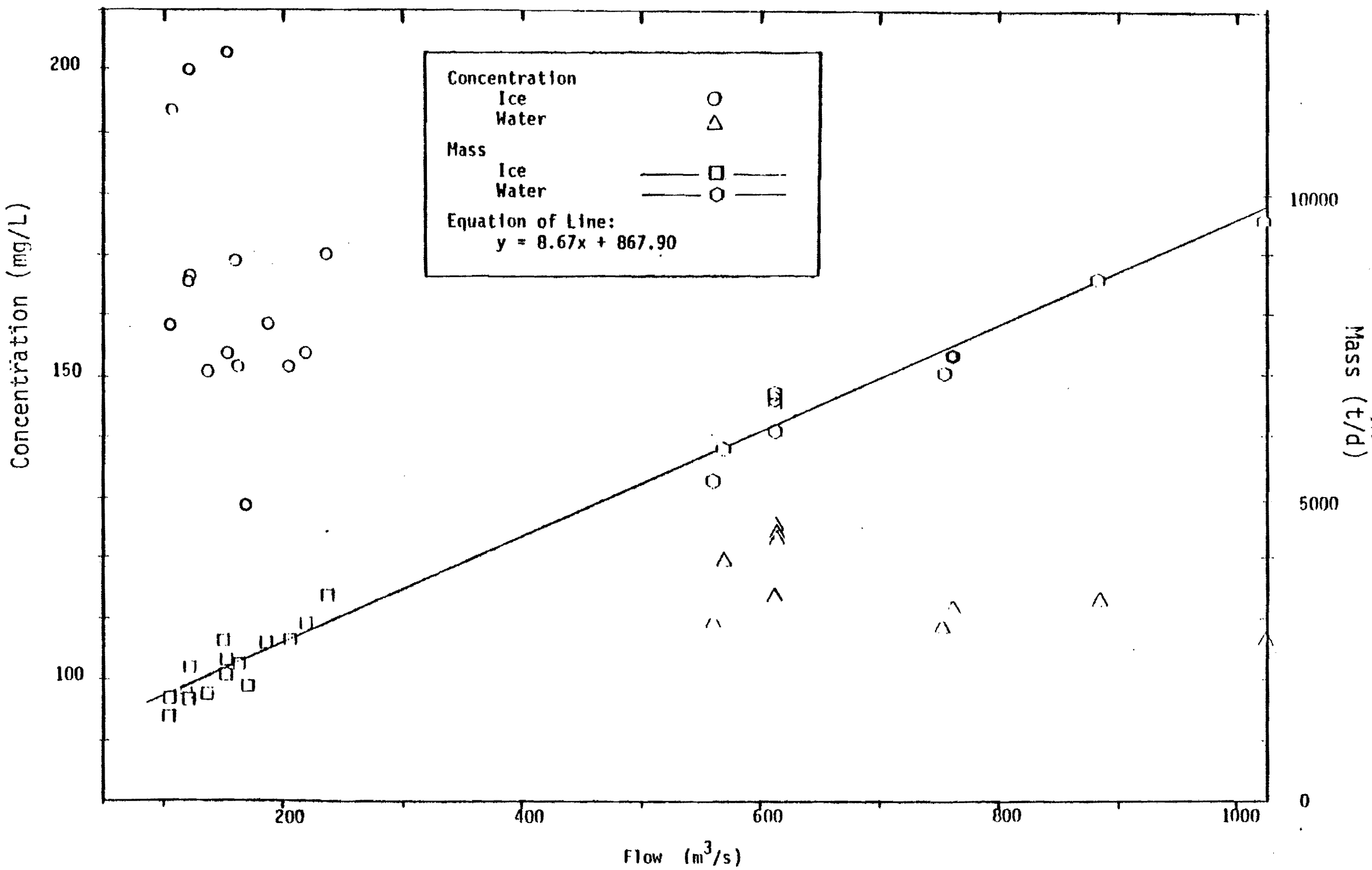


Figure 55. Total hardness vs. flow: Athabasca River above Horse River.

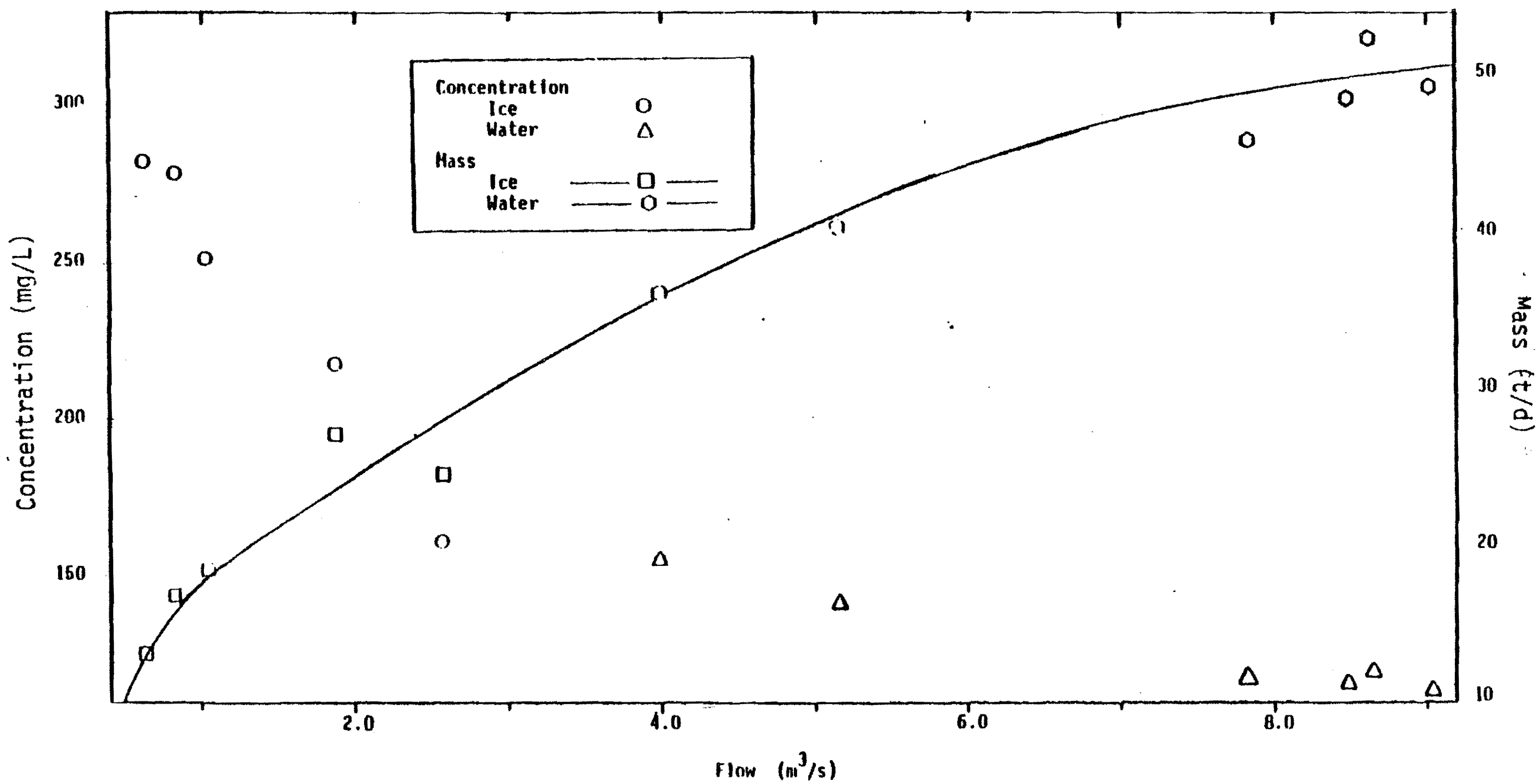


Figure 56. Total hardness vs. flow: Horse River.

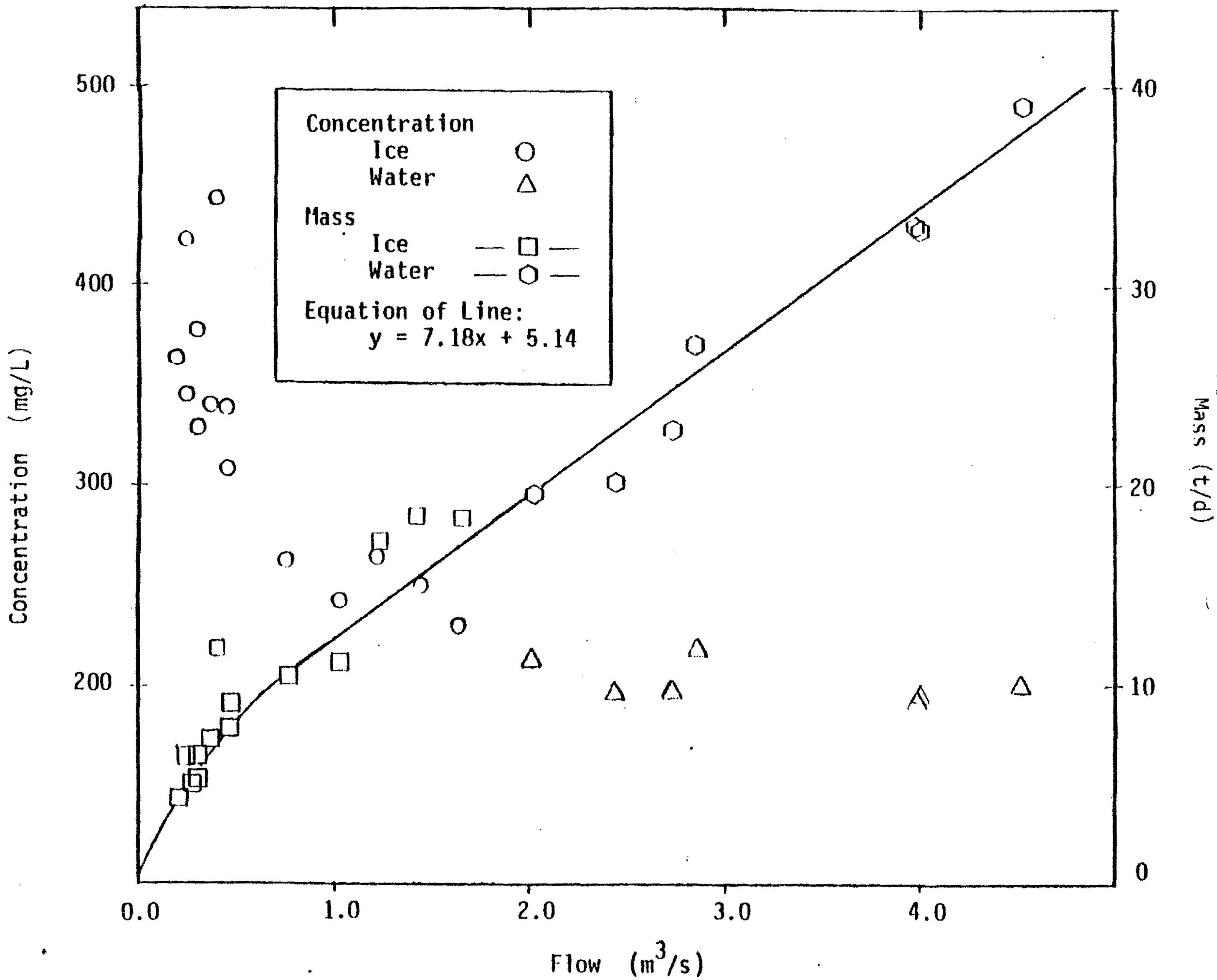


Figure 57. Total hardness vs. flow: Hangingstone River.

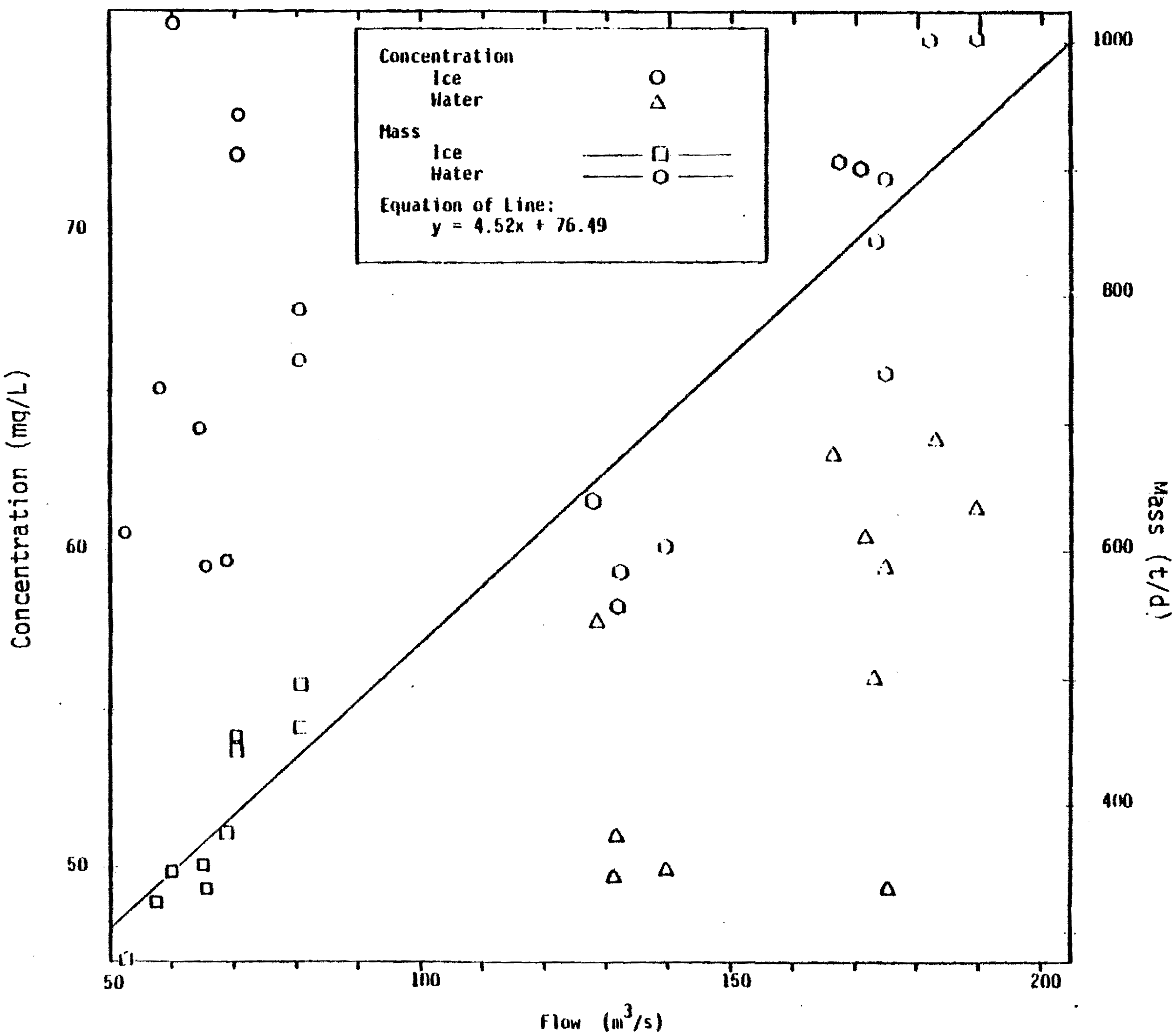


Figure 58. Total hardness vs. flow: Clearwater River.

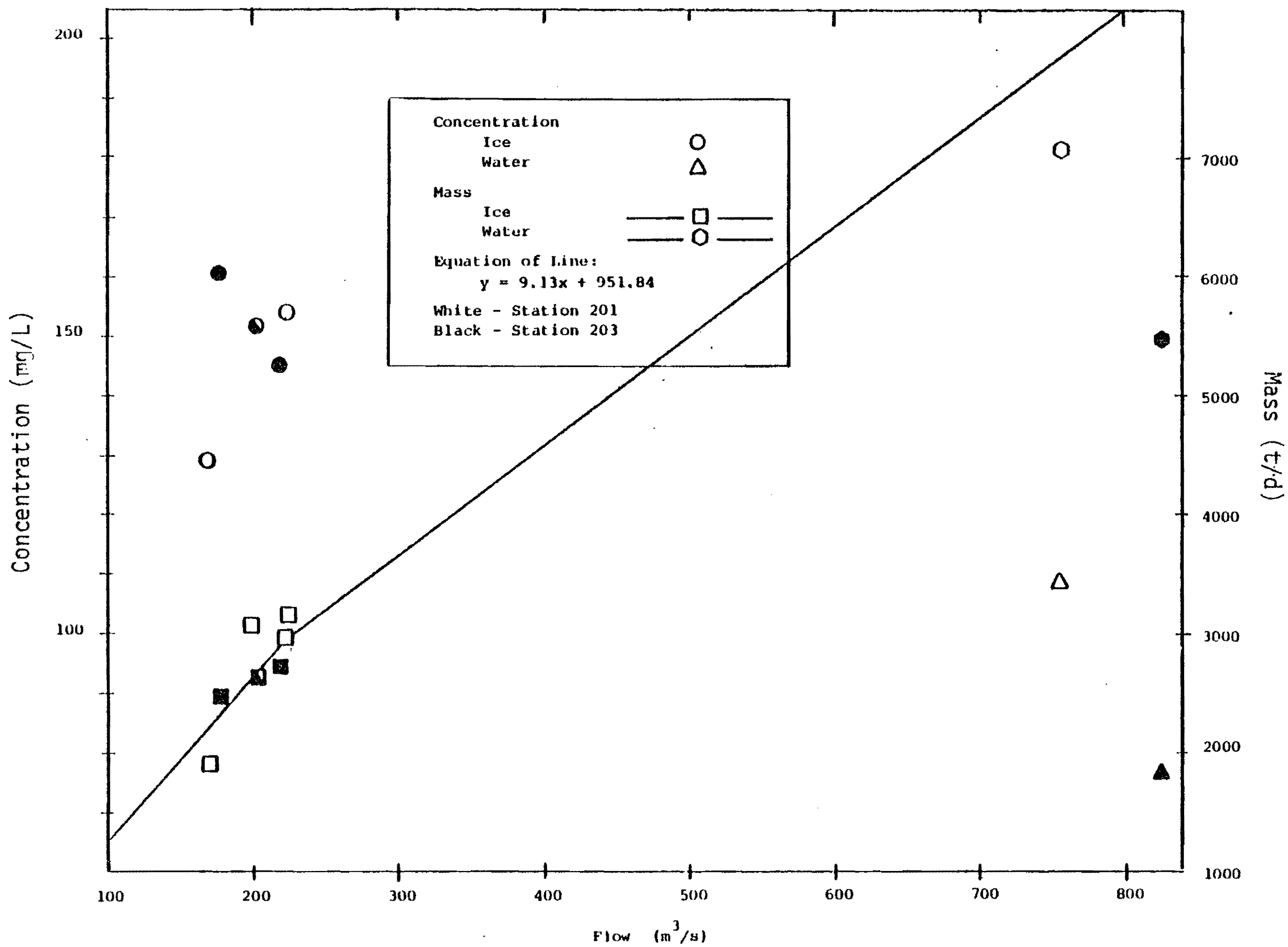


Figure 59. Total hardness vs. flow: Athabasca River between Clearwater River and Poplar Creek.

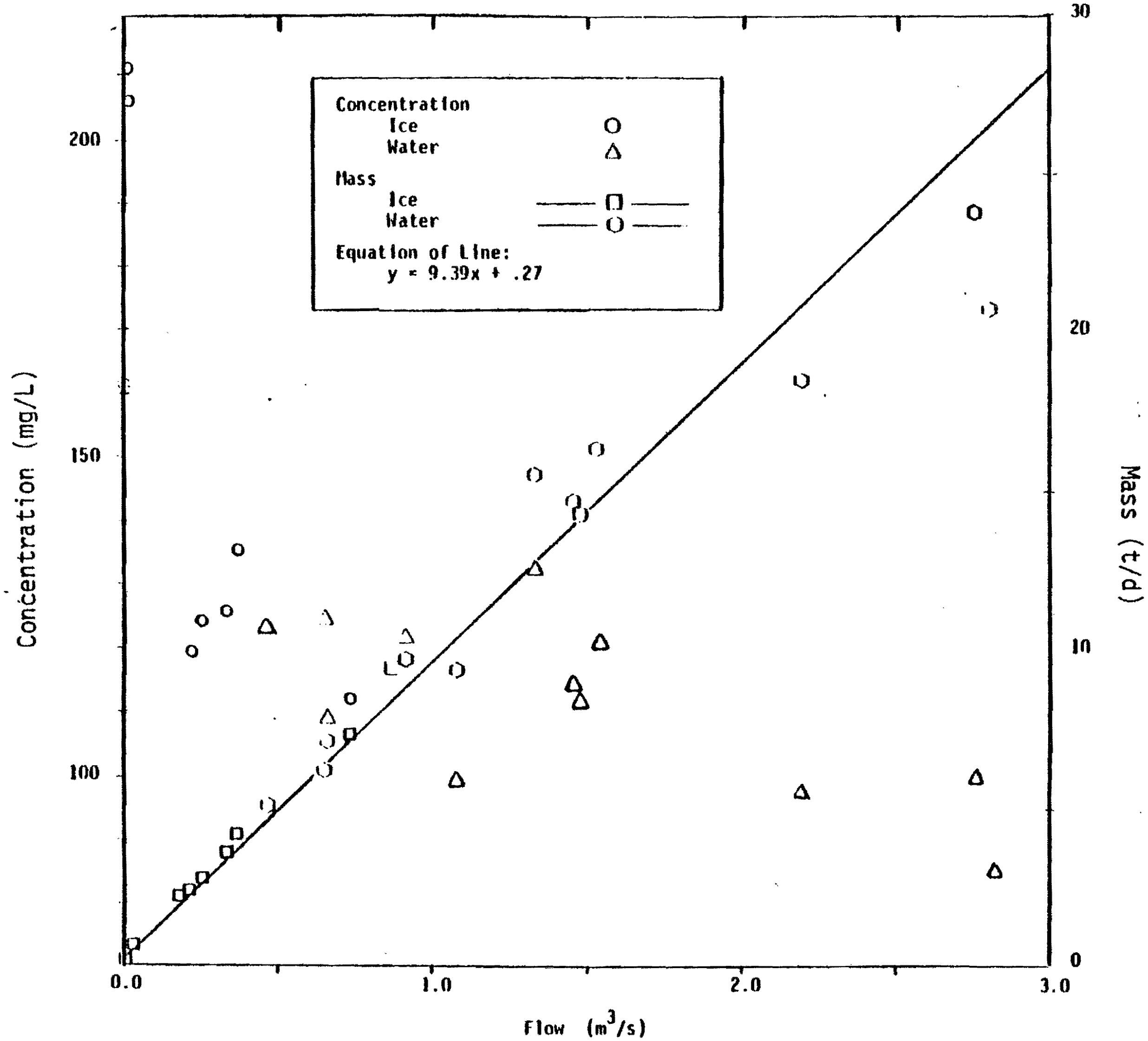


Figure 60. Total hardness vs. flow: Poplar Creek.

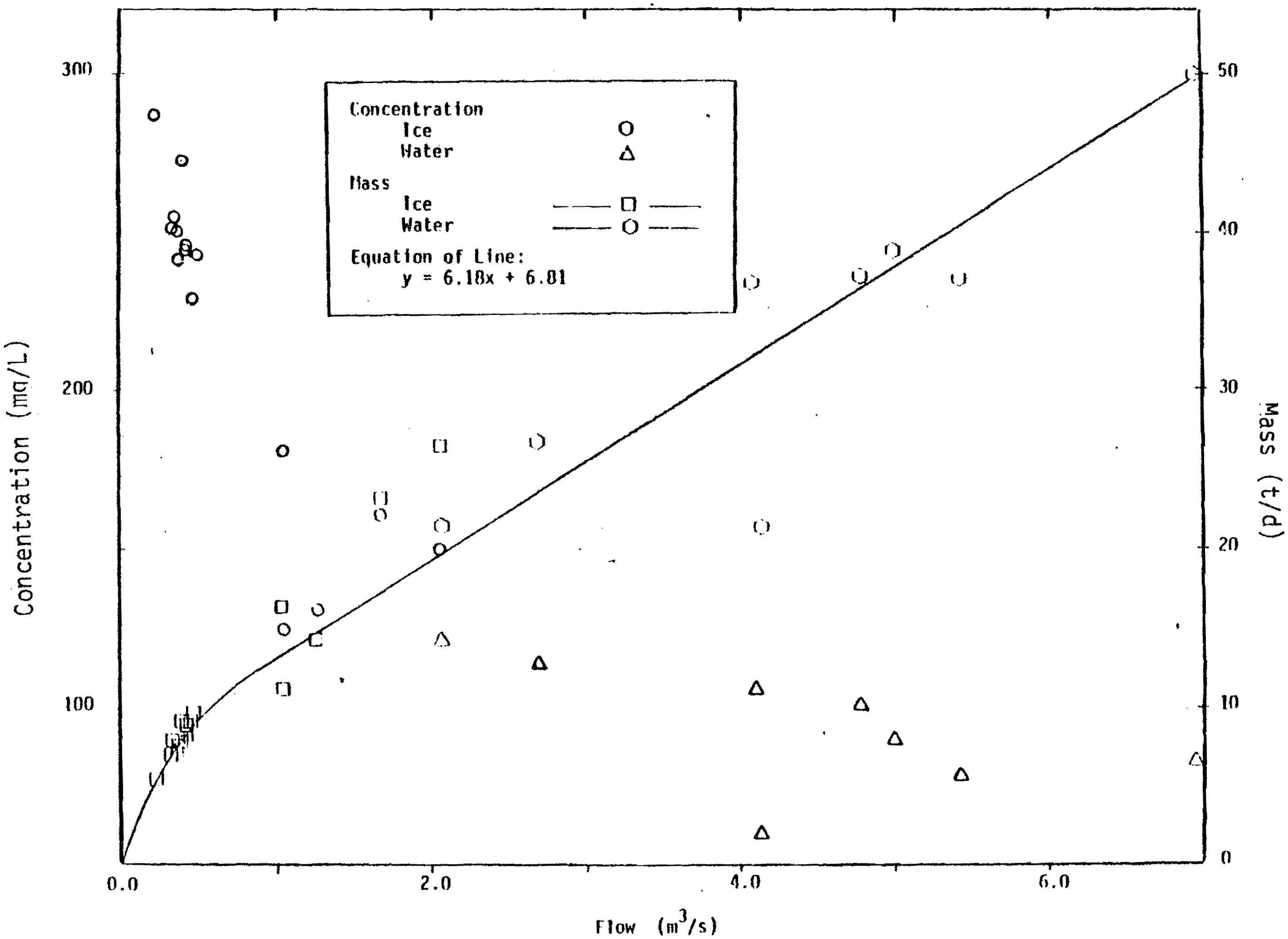


Figure 61. Total hardness vs. flow: Steepbank River.

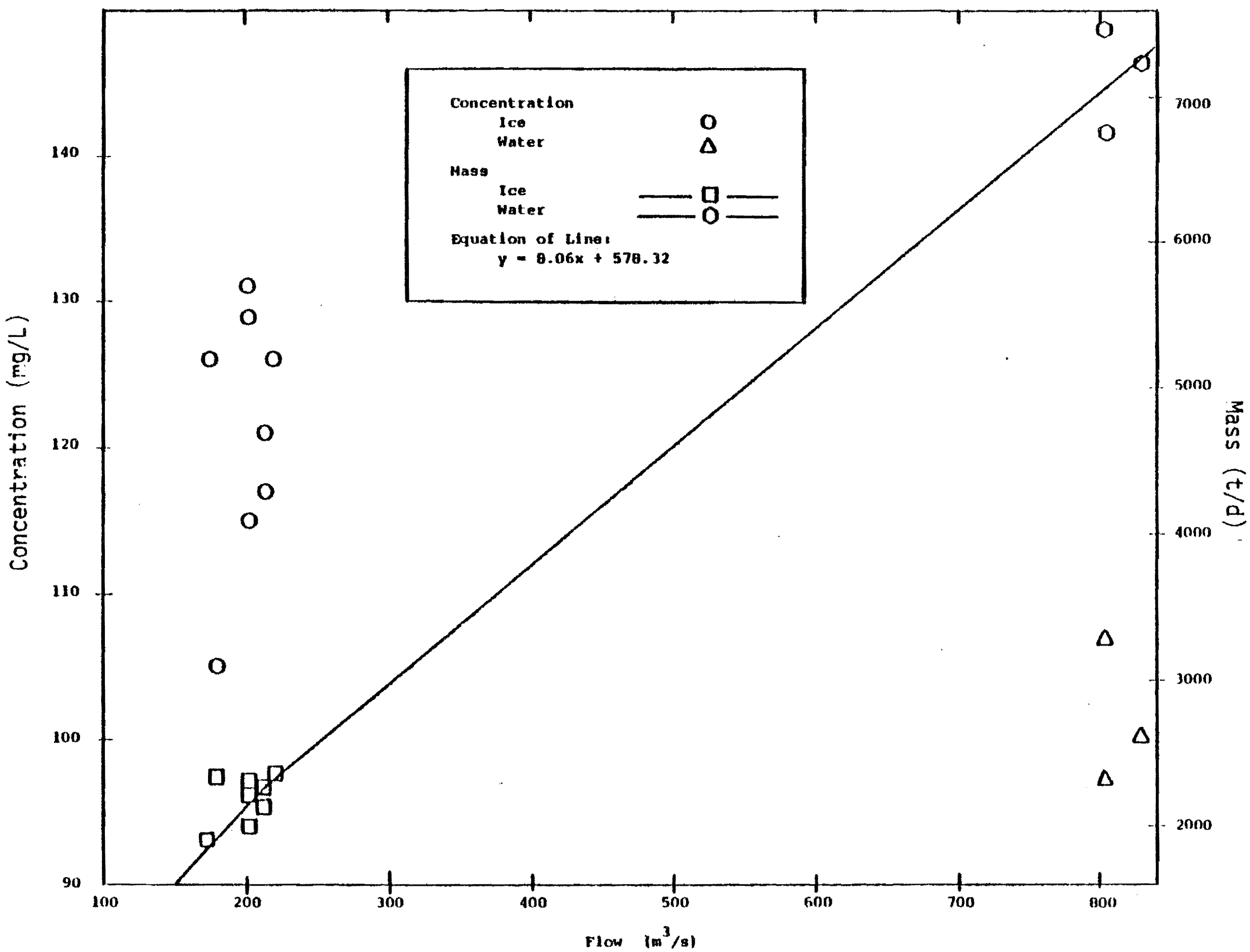


Figure 62. Total hardness vs. flow: Athabasca River between the Steepbank and Muskeg Rivers.

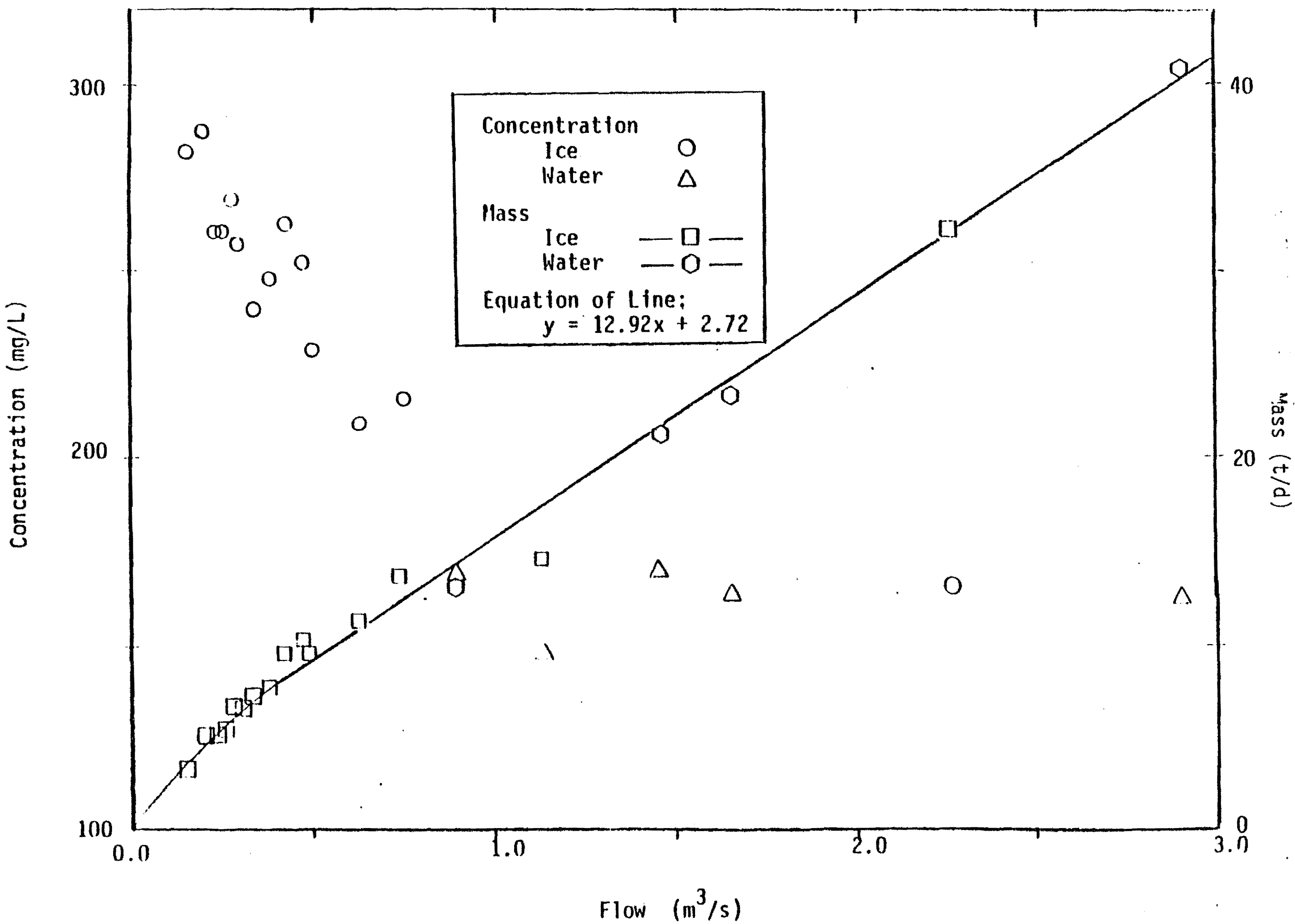


Figure 63. Total hardness vs. flow: Muskeg River.

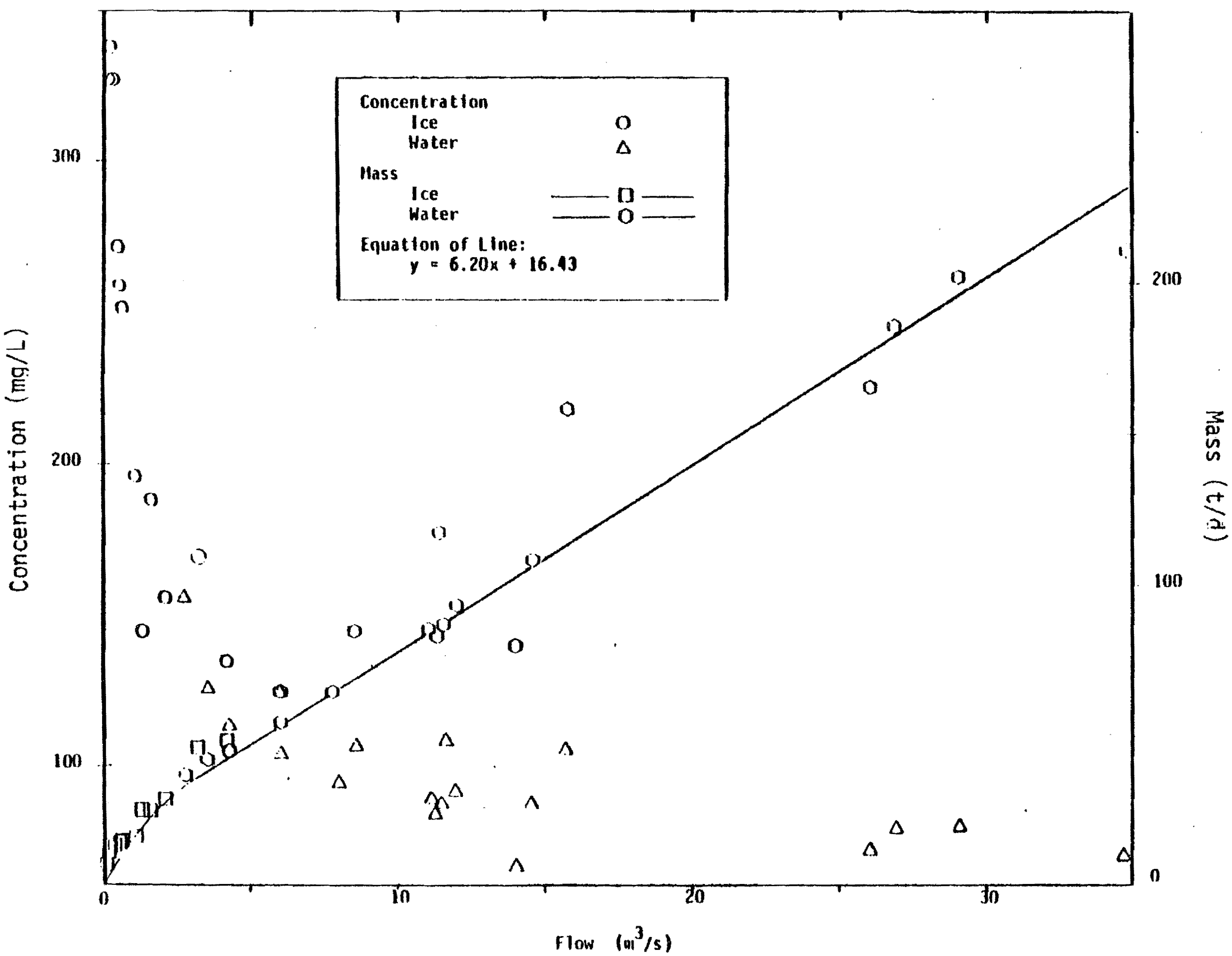


Figure 64. Total hardness vs. flow: Mackay River.

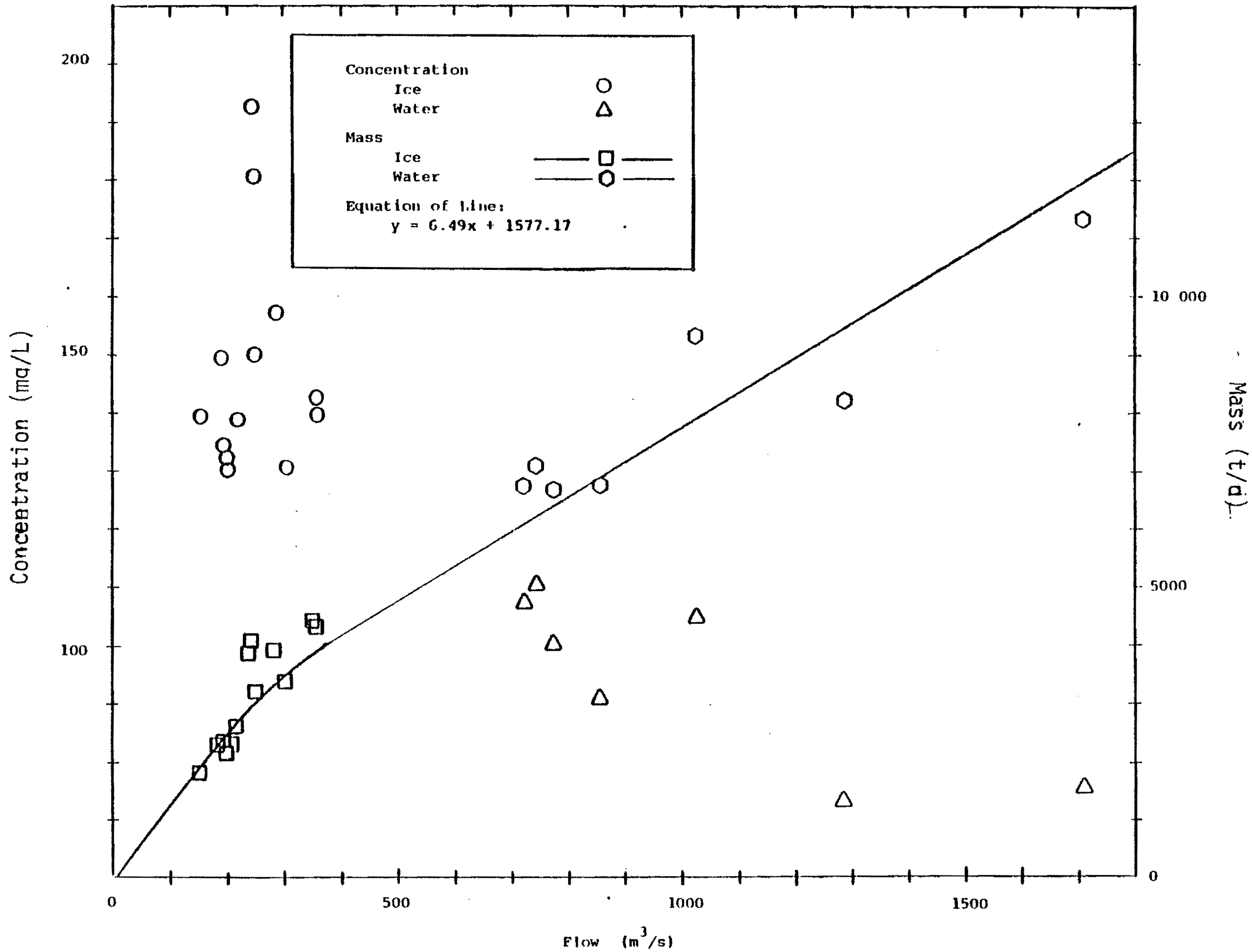


Figure 65. Total hardness vs. flow: Athabasca River below Mackay River.

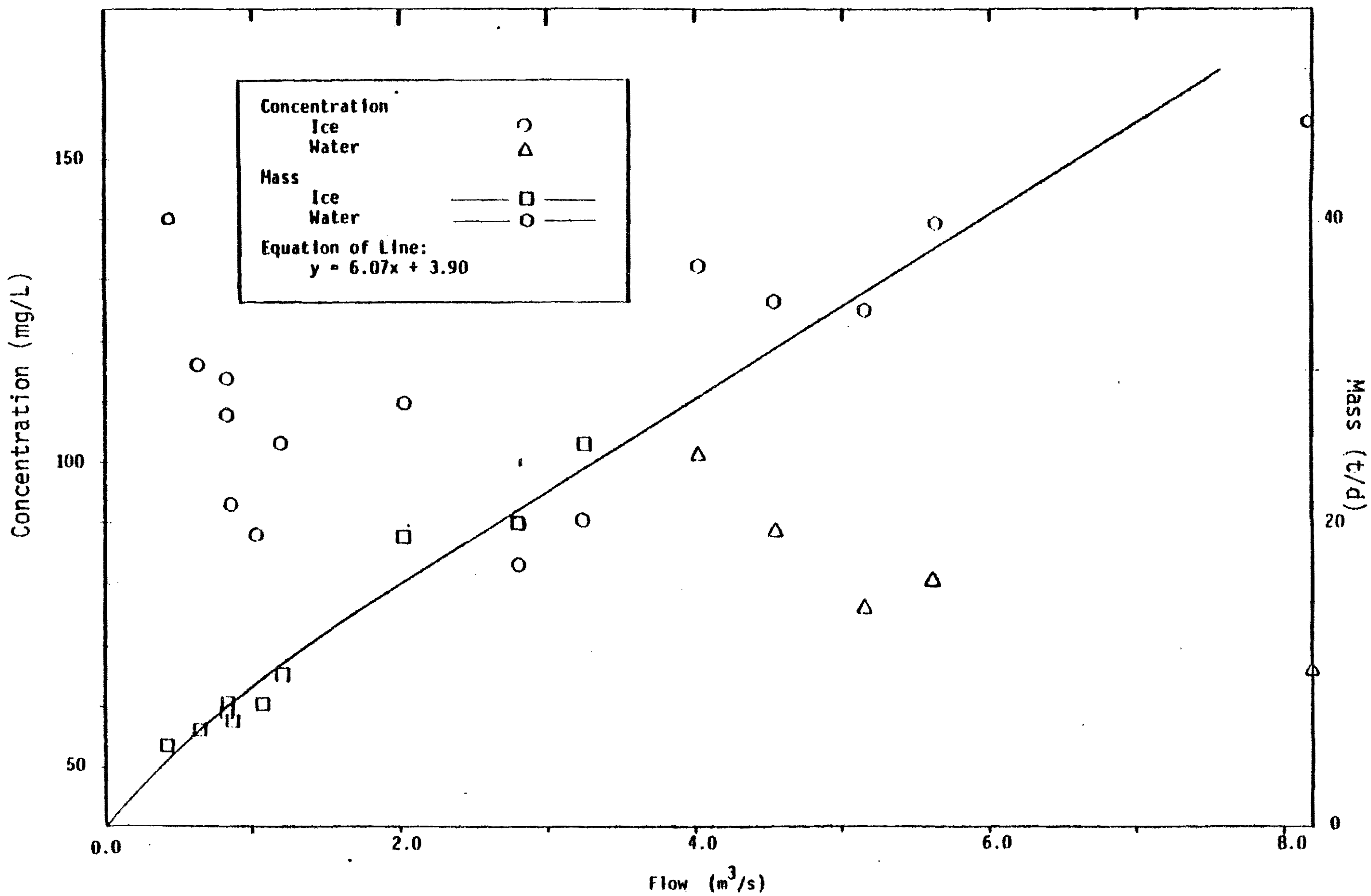


Figure 66. Total hardness vs. flow: Ells River.

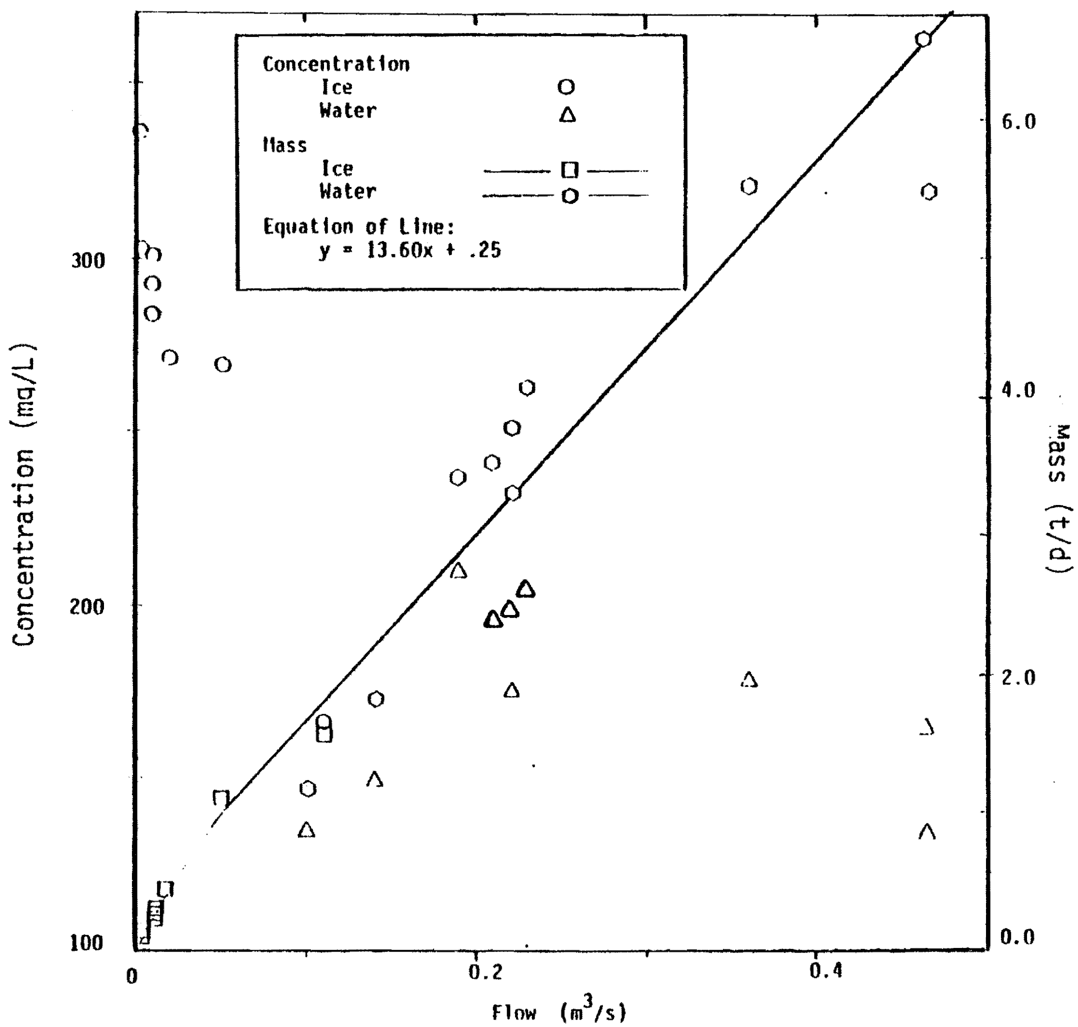


Figure 67. Total hardness vs. flow: Joslyn Creek.

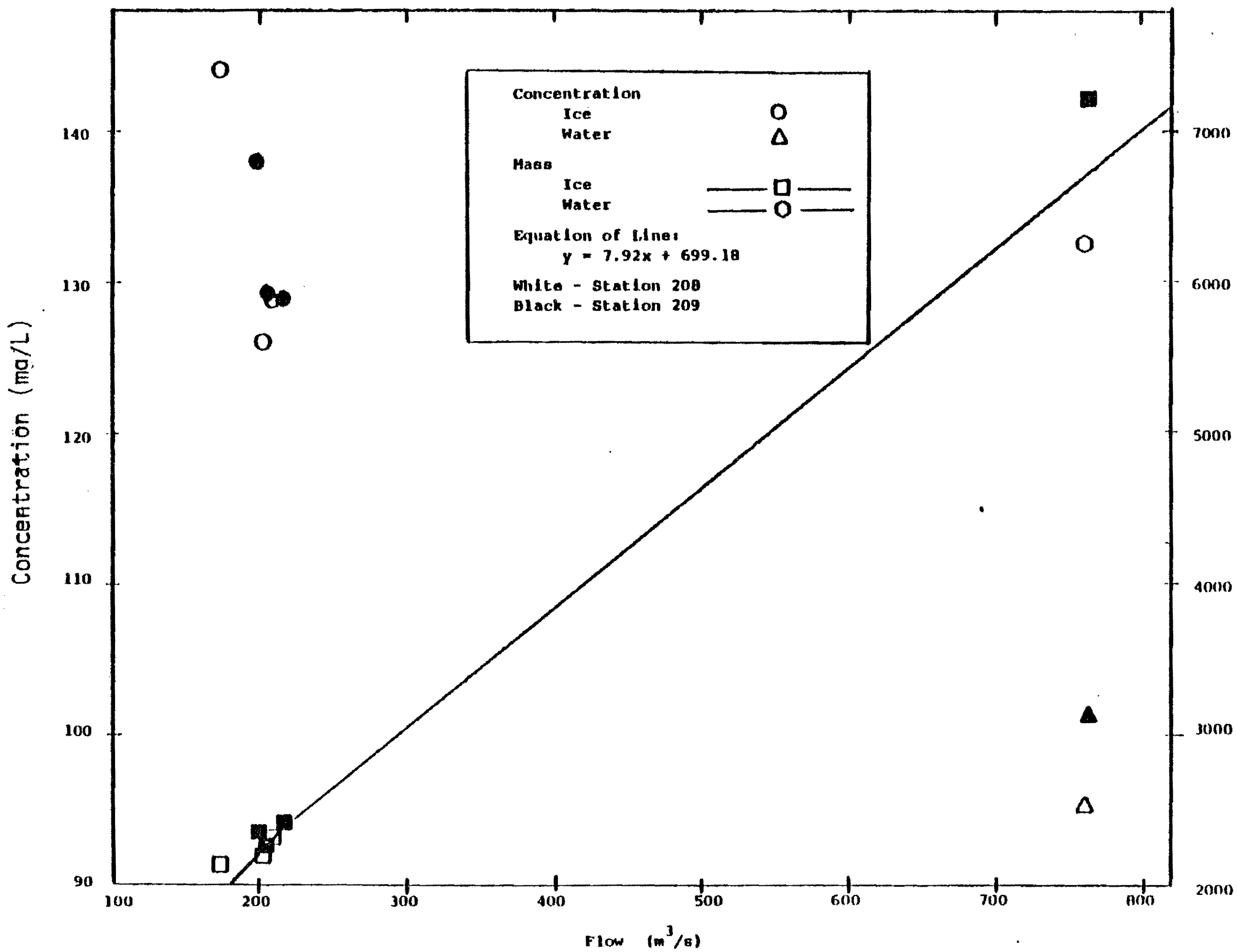


Figure 68. Total hardness vs. flow: Athabasca River between Joslyn Creek and Firebag River.

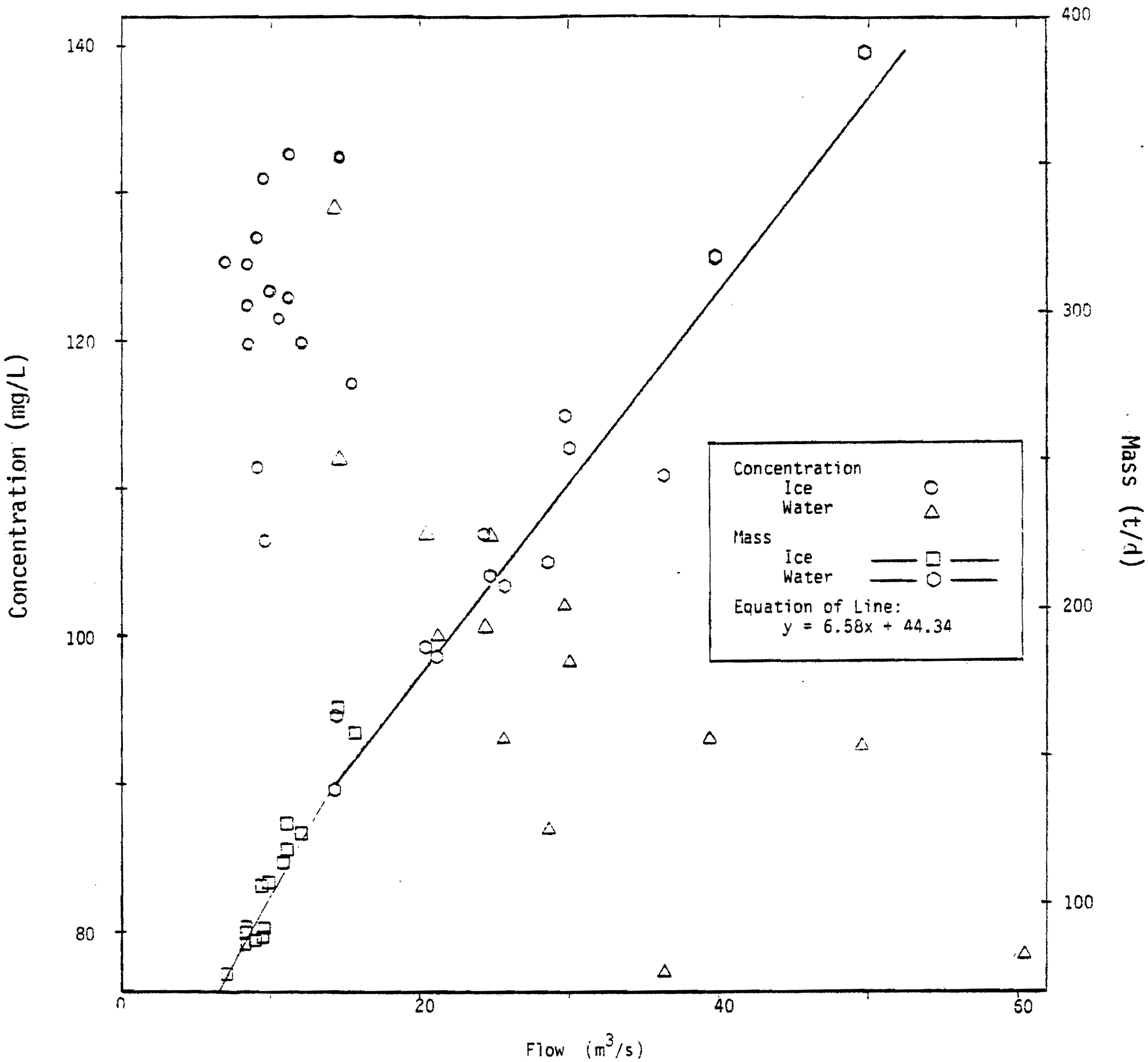


Figure 69. Total hardness vs. flow: Firebag River.

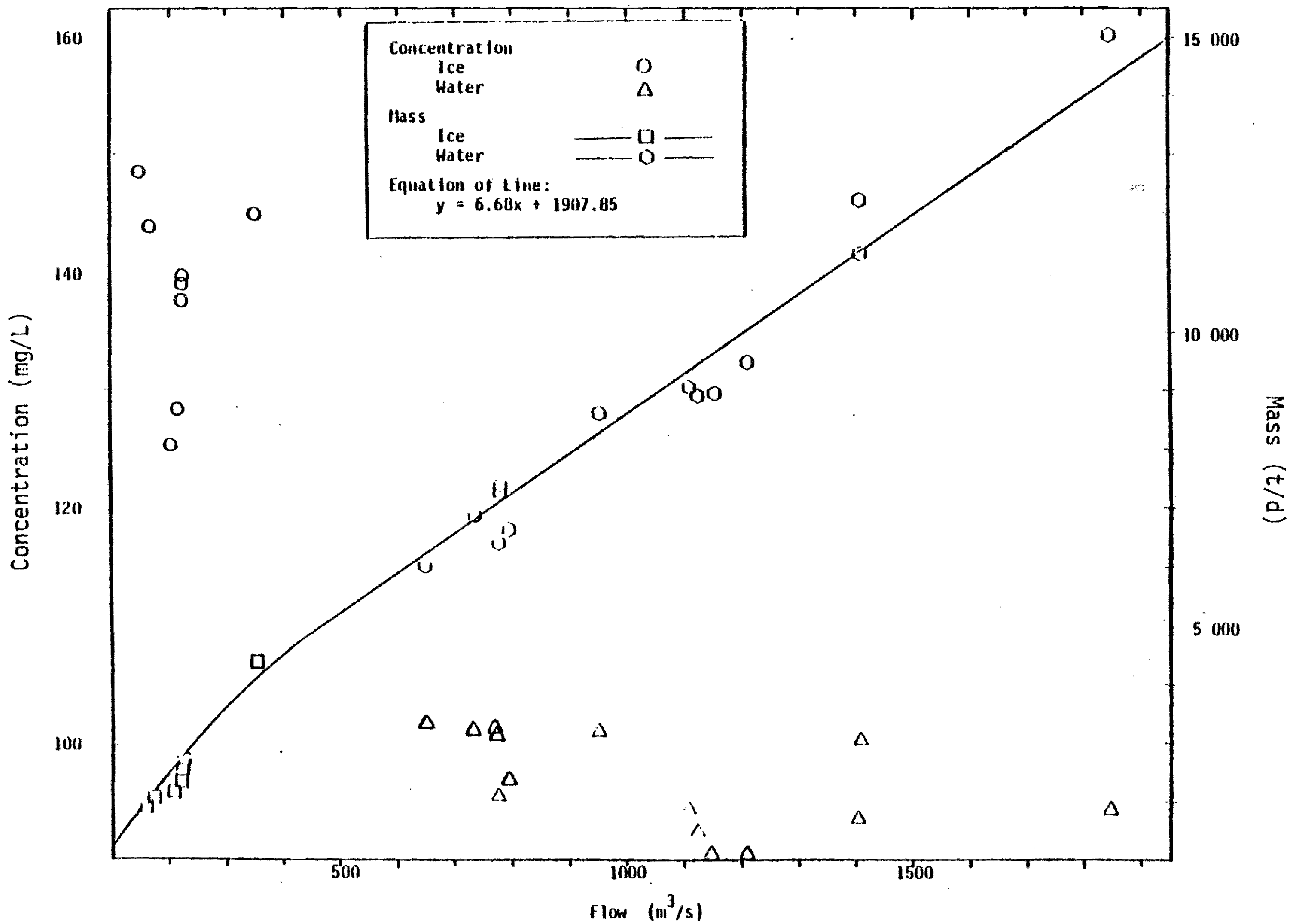


Figure 70. Total hardness vs. flow: Athabasca River at Embarras.